CORRELATED BIOSTRATIGRAPHY AND PALAEOECOLOGY OF MICROPLANKTON FROM THE BEARPAW FORMATION (CAMPANIAN-MAASTRICHTIAN) OF ALBERTA, CANADA

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By

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ABSTRACT

Marine palynomorph assemblages from the Campanian-Maastrichtian Bearpaw Formation, consisting of 34 genera and 69 species of dinoflagellate cysts and 8 forms of acritarchs, were recovered from a composite section in the Cypress Hills and the Research Council of Alberta Castor borehole in southern Alberta, Canada. Correlation of the sections with magnetostratigraphy and radiometric dates of bentonites within the Bearpaw Formation provided a chronostratigraphic control that enabled correlation between the two sections and the Campanian-Maastrichtian Boundary Global Stratotype Section and Point at Tercis les Bains, France. Correlation of first and last occurrence data of key taxa in the boundary section at Tercis with the same taxa in the studied sections support the placement of the Campanian-Maastrichtian Boundary at the transition between magnetochrons 32n.1n and 31r within the *Baculites baculus* ammonoid range zone of the Western Interior of North America.

Semi-quantitative analyses of the assemblages record the transgressive-regressive episodes of the Bearpaw cyclothem. Increases in the relative abundances of gonyaulacacean cysts, numbers of dinocysts compared to terrestrial palynomorphs and assemblage diversity correlate with transgressive episodes, with the richest assemblages occurring during periods of open, offshore to neritic conditions correlated with the cyclothem's transgressive peak.

Two new species of dinoflagellate cyst are described. The first, Dinoflagellate sp. 1, is a novel taxon, while the second, *Downiesphaeridium* sp. A, is a chorate cyst similar to Mesozoic forms previously ascribed to *Cleistosphaerdium diversispinosum* Davey et al. emend. Eaton et al.

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Dedication

This work is dedicated to the memory of three people:

To my first supervisor, Dr. W.A.S. Sarjeant, polymath and true natural historian, for introducing me to palynology and demonstrating that a Renaissance Man could still be found in the 21st Century;

To my grandmother, Leone Donaldson, for showing me how to seek answers to questions; and

To my son, Liam Dalzell.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
1CS	First Castor Sandstone
2CS	Second Castor Sandstone
C-M	Campanian-Maastrichtian (Boundary)
D:S	Dinocyst to Terrestrial Sporomorph ratio
FO	First occurrence datum
$G:P_{ind}$	Gonyaulacacean to Peridinialean ratio (individual cysts)
$G:P_{sp}$	Gonyaulacacean to Peridinialean Ratio (species)
GMUS	Geological Museum, University of Saskatchewan
GSC	Geological Survey of Canada
GSSP	Global Stratotype Section and Point
LO	Last occurrence datum
RCA	Research Council of Alberta
RTMP	Royal Tyrrell Museum of Palaeontology
S:D	Terrestrial Sporomorph to Dinocyst ratio

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE OF INVESTIGATION

The Bearpaw Formation of Saskatchewan and Alberta has been the subject of on-going interest by a number of workers, mostly with regards to lithostratigraphy, sedimentology and palaeontology of invertebrate and vertebrate macrofauna. The formation consists of sediments deposited during the last major transgressive-regressive sequence of the Western Interior Seaway, a continuum of epeiric seas that dominated the North American mid-continent throughout most of the Mesozoic. Despite a considerable volume of work involving the Bearpaw Formation throughout much of the last forty years, much with regards to the formation's palaeoecology and palaeoceanography still remains poorly understood. In particular, several questions remain concerning the biostratigraphy of the formation correlated against global geologic events and absolute time. Thus, this thesis has the following objectives:

- Refine and update the marine palynostratigraphy of the Bearpaw Formation in Alberta and correlate it with palaeomagnetic information to produce a dinoflagellate magnetobiostratigraphy; and
- Determine if the resulting magnetobiostratigraphy could be utilized to clarify the position of the Campanian-Maastrichtian boundary in the Western Interior of North America.

1.2 RATIONALE

The objectives of this investigation are attainable due to a number of advances since the initial studies of organic-walled microplankton from the Bearpaw Formation and coeval strata during the 1970's (Harland, 1973, 1977; Harker, 1977). Improvements in dinoflagellate cyst systematics and palaeoecology permit a more rigorous, biostratigraphically-oriented approach to the interval than has been possible previously. The selection of the Campanian-Maastrichtian Global Stratotype Section and Point (GSSP) at Tercis les Bains near Landes in southwest France (Odin and Lamaurelle, 2001) also provides the opportunity to correlate the boundary interval in the Western Interior Basin with an unequivocal global standard. The selection of sample localities that represent almost the entire vertical extent of the Bearpaw Formation in southeastern Alberta, combined with geochronological information based on magnetostratigraphy and radioisotopes further reinforces the biostratigraphy and permits correlation based on independent time markers.

In Alberta, the Bearpaw transgression flooded across a deltaic plain that was home to an extremely diverse fauna and flora that was preserved as the Dinosaur Park Formation of the Belly River Group. The regression of the Bearpaw Sea was diachronous, with 'pulses' of marine inundation occurring in the area throughout the deposition of the subsequent Horseshoe Canyon Formation (Edmonton Group). Both terrestrial formations have been the subject of intensive palaeontological and sedimentological inquiry. In particular, the terrestrial sediments adjacent to the Bearpaw are the subject of on-going research regarding the palynology and magnetobiostratigraphy of terrestrial palynomorphs (spores and pollen) and subsequently

derived palaeoecology (Lerbekmo and Braman, 2002; Lerbekmo et al. 2003; Braman and Koppelhus, 2005). Knowledge of this sequence is broadened and complemented by a similarly improved understanding of the marine realm as recorded by microplanktonic dinoflagellate cysts and acritarchs.

Both dinoflagellate and acritarch cysts have proven to be useful in stratigraphy, particularly of Mesozoic sediments, including the Bearpaw Formation. Harland (1973, 1977) first reported the recovery of dinoflagellates and acritarchs from the Bearpaw Formation in western Canada and Montana. Harker (1977) later developed a biostratigraphy based on dinoflagellates for the Campanian of Saskatchewan and Manitoba (Lea Park, Bearpaw and Riding Mountain formations) as part of his comparison of the palynoflora of the northern plains with that of the Gulf coast of Texas and the central plains of Wyoming.

1.3 THE CAMPANIAN – MAASTRICHTIAN BOUNDARY

The location of the Campanian – Maastrichtian (C-M) boundary has been a contentious issue amongst stratigraphers, particularly with regards to its stratigraphic position within the Western Interior of North America (Obradovich, 1993). This was due in part to the difficulty in correlating ammonoids and belemnites endemic to the Western Interior with the two cephalopod species traditionally used to define the Campanian and Maastrichtian intervals in Europe, the last occurrence of *Nostoceras hyatti* and the first occurrence of *Belemnella lanceolata* (Odin, 2001).

Jeletzky (1968) first proposed that the C-M boundary be placed at the base of the *B. baculus* Zone, which was adopted by Caldwell (1968) and Harland (1973 and 1977). Later, Obradovich and Cobban (1975) placed the boundary lower at the base of the *B. reesidei* Zone, which was adopted by Caldwell et al. (1978) and Harker et al. (1990).

Kurita and McIntyre (1994) suggested that the position of the boundary lay somewhere between these two extremes, placing it between the *Baculites jenseni and B. eliasi* Zones. This placement was supported by McArthur et al. (1992, 1994) based on their measurements of $^{87}Sr/^{86}Sr$. Lerbekmo and Braman (2002) suggested returning the boundary to the base of the *Baculites baculus* Zone, at or near the 31r – 32n boundary, a conclusion that had also been arrived at independently by Gradstein and Ogg (2004). Table 1.1 summarizes some of the biozones that have been proposed to contain the boundary interval.

Table 1.1: Summary of ammonoid biozones possibly containing the C-M boundary in the Western Interior of North America.

AMMONOID ZONE	AUTHORS
B. baculus	• Jeletzky (1968) (ammonoid biostratigraphy) • Hancock and Kauffman (1989) (global eustacy) • Lerbekmo and Braman (2002) (magnetostratigraphy)
B. eliasi	• Obradovich (1993) (geochronology) • Kurita and McIntyre (1994) (geochronology, palynology)
B. jenseni	• Kennedy et al. (1992) (ammonoid biostratigraphy), • McArthur et al (1992) (Sr curve)
B. reesidei	• Obradovich and Cobban (1975) (ammonoid biostratigraphy, geochronology)

1.3.1 Placement of the global Campanian-Maastrichtian type section

In 2001, the Global Stratotype and Boundary Section for the Campanian-Maastrichtian (C-M) interval was placed at Tercis les Bains in southern France, based on the occurrence of 12 biohorizons in the section. These included the last occurrences of the dinoflagellate cysts *Corradinisphaeridium horridum, Raetiaedinium truncigerum, Samlandia mayii* and *Samlandia carnarvonensis* (Odin and Lamaurelle, 2001). Although none of these dinoflagellate taxa have been recovered from the Bearpaw Formation, Antonescu, et al. (2001a, 2001b), Siegl-Farkas (2001), and Schiøler and Wilson (2001) reported sixteen other dinoflagellate biosignals, including the first and last occurrences of

taxa reported from the Bearpaw Formation and other coeval strata within the Western Interior, specifically:

- Last Occurrence (LO) of the genus *Odontochitina;*
- LO of the genus *Xenascus;*
- LO of the genus *Subtilisphaera;*
- LO of *Palaeohystrichophora infusorioides;*
- LO of *Dinogymnium accuminatum;*
- LO of *Chatangiella? robusta;*
- First Occurrence (FO) of *Cerodinium diebelii;*
- FO of *Alterbidinium minor* and a form identified as "*Alterbidinium cf. acutulum"*(Schiøler and Wilson, 2001)*;*
- FO of *Trithyrodinium evittii;* and
- FO of *Microdinium carpentiare*.

It is anticipated that the assemblages reported in this study will provide further insight into the position of the C-M boundary in the Western Interior of North America.

Conversely, magnetobiostratigraphic information from this study complements the stratotype at Tercis, which was found to be lacking useful palaeomagnetic data, requiring correlation of the locality with palaeomagnetically useful strata in the Bottaccione Gorge region, Italy (Lewy and Odin, 2001). The correlation of these two sections relied on the presence of magnetozone 33n in both sections and a common assemblage of foraminifera for the overlying strata, with the C-M boundary placed at the 32n – 31r transition. The same palaeomagnetic interval was identified by Lerbekmo and

Braman (2002) and Lerbekmo et al. (2003) in the *B. baculus* Zone of the Cypress Hills, Red Deer Valley and Castor (Battle River) sections of Alberta.

1.4 STUDIED TAXA: DINOFLAGELLATES AND ACRITARCHS

Organic-walled microplankton are the persistent remains of vegetative and reproducrtive cysts of unicellular planktonic organisms and are grouped along with spores and pollen as palynomorphs. The resistant nature of the material that composes these cysts permits excellent preservation in the rock record in a variety of sediments, including those that have undergone low-grade metamorphism (Sarjeant, 1974) and were first identified by Ehrenberg in 1836 as 'hystrichospheres'(Sarjeant, 1970). In the twentieth century, workers attributed most of these hystrichosphaera to the remains of extant groups such as the dinoflagellates (Kingdom Protista, Division Dinoflagellata) (Evitt 1961, 1963a and b; Evitt and Davidson, 1964; Wall and Dale, 1970; Fensome et al. 1993). Those forms not attributable to known groups of algal plants or protists were placed in the non-phyletic Group Acritarcha (Downie, Evitt and Sarjeant, 1963).

1.4.1 Dinoflagellates – General Remarks

Dinoflagellates are an extremely diverse group of unicellular organisms, most popularly known from the toxic red tides and 'sea sparkle' that are produced by the blooms of some genera. Their name, from the Greek for *whirling whip*, is due to the two flagella that members of the group possess for at least part of their lifecycle. One flagellum extends posteriorly from the organism along a longitudinal furrow called the *sulcus*. The other flagellum wraps laterally around the body in a transverse furrow or *cingulum*. The combined motion of these two flagella imparts a spinning motion to the

organism as it is propelled through the water. The dinoflagellates of interest to palynology are placed in Class Dinophyceae of Subdivision Dinokaryota (Fensome, et al. 1993).

Resistant cysts of the complex organic macromolecule dinosporin are formed by dinoflagellates as part of reproductive cycles, as vegetative cysts and as refugia during periods of resource scarcity. Excystment is accomplished through an archeopyle, after which the cyst may become buried in benthic sediments. Archeopyle location, shape, size and method of formation, such as an operculum or removal of a section of the cyst theca, are key diagnostic factors.

Both living cells and fossil cysts are described with terminology related to the living motile form (Figure 1.1), with the apical or anterior end being in the direction of travel if the cell was travelling vertically in the water column. The ventral surface is identified by the sulcus and the insertion points of the two flagella. The cingulum divides the dinoflagellate latitudinally into the upper (or anterior) epitheca and lower (or posterior) hypotheca. Cyst terminology is similar, with the prefixes 'epi' and 'hypo' preceding 'cyst' or 'tract'. The apex, antapex, cingulum and sulcus are often used as reference points when discussing motile cell and cyst morphology. Latitudinal series of plates (on living cells) or paraplates (on cysts) are numbered from the ventral midline along the sulcal axis, moving to the right around the organism.

The tabulation of motile cells and the paratabulation of cysts, when present, is an important diagnostic feature and has lead to the development of several tabulation schemes by taxonomists and systematicists, defined by latitudinal series of plates into tabulation formulae (e.g. Kofoid, 1909; Eaton, 1980; "Taylor-Evitt" *in* Fensome et al.

1996). This study has chosen to rely on the Kofoid tabulation scheme for its general acceptance, ease of application, simple terminology and its avoidance of assumed plate homologies, which are subject to the interpretative biases of the authors who proposed them and offer little in the way of biostratigraphic utility.

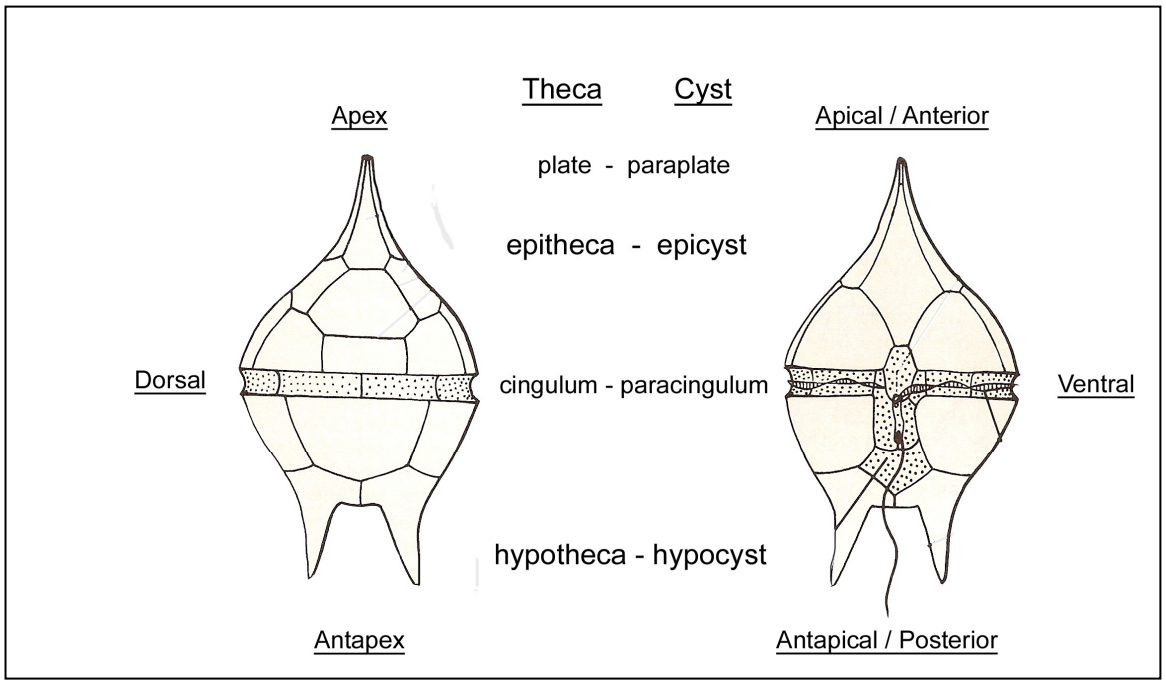


Figure 1.1: General illustration of a peridinialean dinoflagellate, with terminology used in relation to the motile theca and cyst. (Adapted from Evitt, 1985).

Cysts form within the plasma membrane and are classified into four groups based on the proximity of the cyst to the cell wall. Proximate cysts form in direct contact with the cell wall and thus closely reflect the original tabulation of the organism's amphiesma. Chorate cysts form within the cytoplasm at a distance from the cell wall, maintaining contact with the cell wall through processes that are used as diagnostic features, both in their own right and as the basis for hypothetical tabulation formulae. The proximochorate cyst, used by some workers, is considered to be an intermediate form between the proximate and chorate morphotypes. Cavate cysts, like proximate cysts, also form close

to the cell wall, but possess distinct wall layers, the outer pericyst and inner endocyst, separated by one or more pericoels that extend into apical and antapical horns.

1.4.2 Taxonomic Overview

Dinoflagellates have adapted to a wide array of life habits and ecological niches, including free-living holotrophs and heterotrophs, colonial forms, parasites (such as the notorious genus *Pfisteria*) and as zooxanthellae symbionts in corals and some bivalves. Of interest to this study are taxa contained within the subclasses Peridinophycidae and Gymnodiniphycidae.

Subclass Peridiniphycidae Fensome et al. 1993

The Peridiniphycidae compose the majority of the dinoflagellate fossil record (Fensome et al., 1993). Peridiniphycids are free-living motile cells during most of their lifecycles, forming resistant dinosporin cysts as refugia and as hypnozygotes. The holotrophic motile cells are contained within thecae of interlocking plates. The subclass contains two significant fossil orders: the Peridiniales and Gonyaulacales. These two orders are differentiated primarily on the basis of tabulation patterns.

Order Peridiniales Haeckel 1894

The peridinialeans generally exhibit a bilaterally symmetrical 'peridinoid' tabulation pattern similar to the extant genus *Peridinium*. This features a symmetrically-shaped first apical plate (or homologue), an even number of apical plates (usually four), four anterior intercalary plates, seven precingular and five postcingular plates and two antapical plates. The sulcus is composed of four plates. The cingulum, often the only reliable evidence of tabulation on many dinocysts, is a continuous equatorial band. Exceptions to this pattern

exist, usually in terms of the number of plates within a series, but these deviations are considered to be derived features and are used by systematicists for suprageneric classification and phylogeny.

Peridinoid cysts are proximate or cavate in form, with ornamentation generally restricted to marginal frills or short spines at plate boundaries and reticulate or scabrate textures intratabularly. Most peridinoids also exhibit some form of apical and antapical horns, giving them a somewhat pentagonal outline or ambitus.

Order Gonyaulacales Taylor 1980

The gonyaulacaceans typically exhibit an assymetrical 'gonyaulacoid' tabulation due to the presence of an asymmetrically-shaped first apical plate and a single antapical plate. The plate series typically include four apical plates, no anterior intercalary plates, a precingular series of six plates, six cingular plates, six postcingular plates, the first of which is conspicuously larger than the others in the series, a single posterior intercalary plate and five sulcal plates in addition to the single antapical plate. The cingulum is not a continuous equatorial belt, but is displaced on the ventral surface at the sulcus by one or more plate widths, with discernible proximal and distal ends.

Gonyaulacoid cysts are most notably chorate and proximochorate in form, with processes radiating from a spherical to ovoidal vesicle. Proximate forms are also common, such as the extant genus *Gonyaulax.* In the case of chorate and proximochorate cysts, tabulation may be evident as marginal septa between processes (such as in the genera *Spiniferites* and *Pterodinium*). Many workers have proposed tabulation formulae for chorate forms lacking such septa, although this practice must be approached with

caution, as any such formula must begin with the assumption that the processes formed intratabularly, with the end of the process communicating with the centre of a thecal plate, or at the junction of plates.

Subclass Gymnodiniphycidae Fensome et al. 1993

The Gymnodiniphycidae are possibly a polyphyletic group (Fensome et al., 1993 p. 43) composed of 'naked' or 'unarmoured' dinoflagellates, possessing a pellicle of amphiesmal vesicles rather than armoured plates of cellulose. The subclass includes heterotrophic, parasitic, symbiotic and holotrophic taxa that occur in a variety of environments including freshwater. Until recently, all taxa of palaeontological significance were contained within the Order Gymnodiniales Apstein 1909. Fensome et al. 1993 erected two other orders, the Suessiales and the Ptychodiscales, based primarily on the morphology of the motile cell. Although this arrangement will be utilized in the systematics section of this study, specific comment on each of these orders will not be undertaken as the taxonomic distinctions used are outside the realm of fossil palynology. Taxa of the genus *Dinogymnium* are the only gymnodiniphycids recovered in this study.

1.4.4 Stratigraphic Range

The stratigraphic range of dinoflagellates definitely extends to the Triassic, reaching their height in diversity during the Cretaceous. The numbers of dinoflagellate taxa that produce dinosporin cysts decreased sharply during the Miocene, with only a small percentage of extant taxa producing any sort of cyst, resistant or otherwise (Evitt, 1985). One species, *Arpylorus antiquus* Calandra emend. Sarjeant, recovered from the

Late Silurian of Tunisia (Calandra, 1964; Sarjeant, 1978) is generally accepted to be a peridinialean dinoflagellate cyst, although it is the only confirmed occurrence from the Palaeozoic. However, occurrences of unique dinoflagellate biomarkers have been reported from Palaeozoic sediments and have been demonstrated to occur in some acritarch taxa (Talyzina et al., 2000; Moldowan et al., 2000). This evidence, combined with the primitive structure of the dinoflagellate nucleus, suggests that the dinoflagellate lineage extends to at least the earliest Palaeozoic.

1.4.5 Acritarchs – General Remarks

The Acritarchs (Group Acritarcha Evitt 1963a and b) are polyphyletic *incertae sedis* that are essentially a hollow organic-walled vesicle of varying shape. The group was erected as a form of taxonomic 'holding pen' for palynomorphs and organic microfossils for which affinity with known fossil or extant groups could not be ascertained, starting with the hystrichospheres that could not be assigned to the dinoflagellates. The group has an extremely long biostratigraphic range, extending from the Proterozoic to the Recent.

Acritarch taxonomy is based strictly on morphology, particularly the overall shape, possession and distribution of processes, ornamentation and the presence and shape of suspected excystment structures (pores, pylomes, lateral tears or opercula). Numbers of subgroups vary, depending primarily on the morphological distinctions used by various workers. However, the 14 subgroups proposed by Downie et al. (1963) are considered to be the basis for all subsequent taxonomies (Strother, 1996). As mentioned previously, many acritarch taxa have a strong dinoflagellate affinity, possessing chemical biomarkers unique to the dinoflagellates. Other acritarch taxa are likely to be algal cysts,

bacterial colonies, egg cases and spores. As affinities of acritarchs are discerned, they are transferred to the appropriate taxonomic group.

Although systematic treatment will be limited in this study to the generic level, acritarch taxa recovered in this study include forms belonging to the subgroups Acanthromorphitae (round vesicles with processes), Polygonomorphitae (vesicles possessing a distinctly polygonal outline; often this subgroup grades into the acanthromorphs), Sphaeromorphitae (simple, spheroid vesicles lacking processes or complex ornamentation) and Nektomorphitae (oblong to fusiform vesicles without processes or extensive ornamentation).

2.0 GEOLOGIC SETTING

The Western Interior sedimentary basin of North America is characterized by a series of transgressive-regressive cycles, resulting in eastward-thickening wedges of marine sediments alternating with complementary westward-thickening wedges of terrestrial sediments that extend from the orogenic belt of the Proto-Cordillera. From the late Albian to earliest Tertiary, the basin was covered during transgressive periods by the Western Interior Seaway that extended from the Arctic Ocean to the Gulf of Mexico and was a confluence of warm Tethyan waters from the south and cooler Boreal waters from the north (illustrated in figure 2.1).

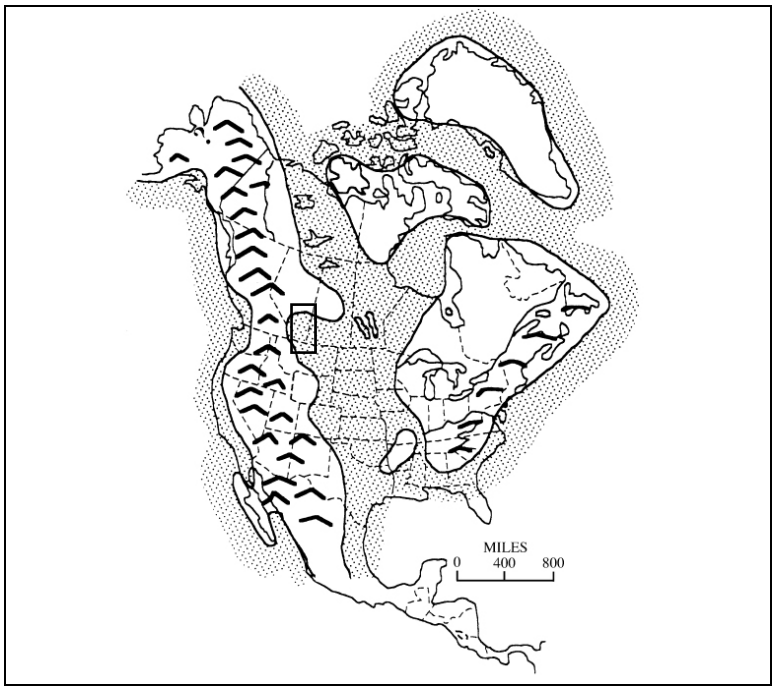


Figure 2.1: Map of North America during the time of the *B. baculus* ammonoid biozone, showing the extent of the Western Interior Seaway (cross-hatched). The study area is identified by a box within an embayment in southern Alberta. From He et al. (2005), based on Williams and Stelck (1975).

2.1 THE BEARPAW FORMATION

The Bearpaw Formation was first described by Hatcher and Stanton (1903). It is an eastward-thickening wedge of marine sediments, consisting mostly of fissile and thin-bedded grey-green shales interspersed with coarse-grained sandstone members, concretionary layers, ash and bentonite beds (Link and Childerhose, 1931; Lines, 1963; Ward et al., 1982; Tsujita, 1995 a and b). In Alberta, the Bearpaw Formation overlies the continental Belly River Group. To the west, the Bearpaw interfingers with several tongues of continental sediments including the Dinosaur Park Formation (Belly River Group), Horseshoe Canyon Formation (Edmonton Group), and the St. Mary River and Whitemud formations in central Alberta. These continental units are preceded by the brackish-marginally marine sediments of the Blood Reserve and Eastend formations (Caldwell, 1968; Catuneanu et al., 1997). To the east, the Bearpaw is contiguous with the Riding Mountain Formation of central Saskatchewan and Manitoba, as well as with the Pierre Shale in Montana and the Dakotas to the south.

2.1.2 Deposition and Stratigraphy

The Bearpaw Formation was deposited during the Campanian as a rapid transgressive event that started in Saskatchewan and moved westward over strata of the Belly River Group into Alberta (Caldwell, 1968). During this time, much of the Canadian prairies were inundated by the terminal Bearpaw cyclothem (T_9-R_9 of Kauffman, 1969) of the epeiric Western Interior Seaway. The Bearpaw Formation extends from eastern Alberta into central Saskatchewan, forming an embayment in southern Alberta. The Riding Mountain Formation, which extends from Saskatchewan east of the Swift Current Arch into Manitoba, represents the centre and eastern margin of the Bearpaw Sea.

Lithologically, the Bearpaw Formation and its constituent members can be divided into two parts: a lower unit consisting of well-bedded marine shale devoid of sandstones and an upper portion, comprising roughly two thirds of the formation that contains three sandstone units separated by shale and siltstone members (Link and Childerhose, 1931; Lines, 1963). This alternation of marine and terrestrial sediments indicates that the regression of the seaway was diachronous, with an ininflux of terrestrial sediments off of the Laramide Orogeny predominantly being deposited during the sea's retreat, only to be replaced by marine sediments during periods of on-lap prior to the seaway's final regression (Catuneanu et al., 1997).

The Bearpaw Formation occurs in limited outcrops in the Cypress Hills and south-central Alberta, and the valleys of the South Saskatchewan, Frenchman, St. Mary's, Red Deer and Bow rivers. Early stratigraphic work based on these exposures was greatly refined by subsurface cores from Castor (Given and Wall, 1971), the Cypress Hills (RCA Thelma) and Strathmore, Alberta (Havard, 1971; Wall et al., 1971), and around Saskatoon (North and Caldwell 1975; Harker, 1977). Composite sections have also been obtained from outcrops near Castor and the valley of the Battle River, Alberta (Given and Wall, 1971), Lethbridge (Tsujita, 1995a and b), Drumheller (Ainsworth, 1994) and the South Saskatchewan River valley (Caldwell, 1968).

At least 22 distinct bentonite beds have been identified, along with several zones that contain ironstone and concretionary nodules. Many of these lithological horizons cannot be reliably traced over long distances due to the intercalation of the Bearpaw Formation with beds of adjacent formations, resulting in several regional lithostratigraphies based on outcrops across Alberta and Saskatchewan.

The samples used in this study were taken from subsurface core and outcrop from the Castor and Cypress Hills sections (refer to Chapter 4). Palaeogeographically, both sections occupied an embayment of the Western Interior Seaway, with Castor near the embayment's north shore and the Cypress Hills localities at the mouth of the embayment in deeper waters. The gradual withdrawal and periodic retrenchments of the seaway during the regressive phase of the cyclothem contributed a north-south component within the embayment in addition to the overall west-east thickening of the marine wedge, resulting in the Bearpaw's deposition terminating earlier in the Red Deer River and Castor sections than in the Cypress Hills. Marine conditions returned briefly to the proximal sections in the form of flooding episodes, brackish swamps and marine tongues within the Horseshoe Canyon Formation (Ainsworth, 1994).

2.1.3 Biostratigraphy and Magnetostratigraphy

Russell and Landes (1940) and Furnival (1941, 1946) reported the biostratigraphic ranges of several key ammonite species from the Bearpaw Formation. Caldwell (1968) recognized that the Bearpaw Formation shared many of the biozones posited by Cobban and others for the United States Western Interior (Gill and Cobban, 1973; Cobban, 1993; Kauffman et al., 1993). Tsujita (1995a and b) and Tsujita and Westermann (1998) revised Caldwell's zonation within the Bearpaw Formation in Alberta. Utilizing both ammonites and benthic macrofauna such as inoceramid bivalves, Tsujita (1995a) correlated outcrops of the Bearpaw Formation across Alberta from the Cypress Hills to the Crowsnest River valley in the Rocky Mountain foothills. This study also confirmed the diachronous nature of the lower Bearpaw contact, except between localities in the St. Mary River valley and

the Cypress Hills, where the Judith River/Bearpaw contact appear to be isochronous (Tsujita 1995a, p. 77).

In Alberta, the base of the Bearpaw Formation is considered to coincide with the base of the *Baculites compressus* ammonoid Zone (Caldwell et al., 1993; Tsujita, 1995a). The formation's upper contact reflects the gradual regression of the Bearpaw Sea, occurring diachronously from roughly west to east across the basin. At its westernmost extreme, the Bearpaw Formation pinches out as early as *Baculites cuneatus* time during the latest Campanian, successively terminating eastwardly within the *B. reesidei*, *B. jenseni*, *B. eliasi* and *B. grandis* zones of the early Maastrichtian (Given and Wall, 1971; Caldwell et al., 1978; Kurita and McIntyre, 1994). As illustrated in Figure 2.2, the Bearpaw Formation in Alberta has its greatest thickness and age range in the Cypress Hills, extending from the base of the *Baculites compressus* Zone to near the top of the *B. grandis* Zone (Caldwell et al., 1993). The section thus represents a period of approximately 4.5 million years, based on the $^{40}Ar/^{39}Ar$ radiometric dates of Obradovich (1993) and interpolations of Kauffman et al. (1993).

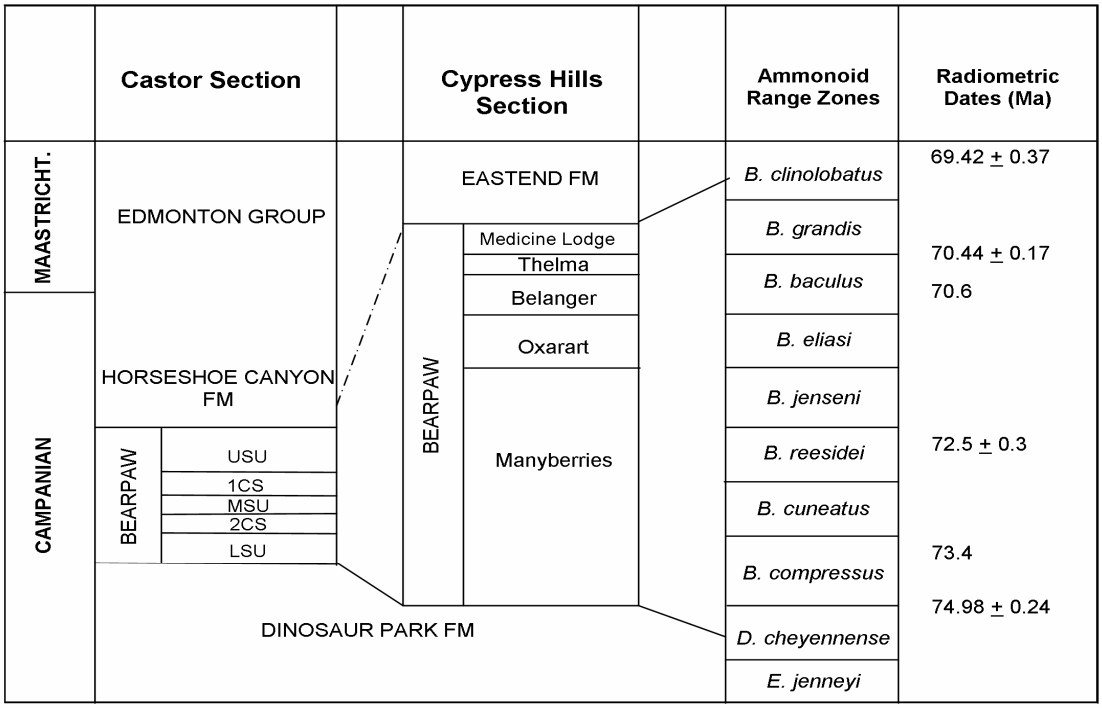


Figure 2.2: Biostratigraphic correlation of the Castor and Cypress Hills sections used in this study with the ammonoid range zones of Cobban (1993) and lithostratigraphies of Given and Wall (1971) and Tsujita and Westermann (1998). Radiometric age of 70.6 Ma for the C-M boundary from Ogg and Smith (2004). Authors of all other radiometric dates are listed in Table 2.1. Abbreviations: USU = upper shale unit; 1CS = First Castor Sandstone; MSU = middle shale unit; 2CS = Second Castor Sandstone; LSU = lower shale unit.

Lerbekmo and Braman (2002) correlated the Red Deer Valley and Cypress Hill sections using magnetostratigraphy and terrestrial palynology. The same approach was used to correlate the Red Deer Valley section with Castor (Lerbekmo et al., 2003). At its greatest vertical extent in the Cypress Hills, the Bearpaw Formation was found to range from the 33n magnetozone at its basal contact with the Dinosaur Park Formation to the 31r/31n transition at its upper contact with the overlying Eastend Formation.

2.1.4 Geochronology

Several bentonite seams from the Bearpaw Formation and adjacent strata have been the subject of K/Ar and $^{40}Ar/^{39}Ar$ radiometric dating by several workers, most often to ascribe dates to biozones considered to potentially contain the Campanian-Maastrichtian boundary in the Western Interior. Jeletzky (1968) first proposed that the Campanian-Maastrichtian boundary occurred within the *B. baculus* Zone, a conclusion that was subsequently supported by Lerbekmo and Braman (2002).

During the intervening years, however, several other candidate biozones were proposed. Obradovich and Cobban (1975) proposed that the boundary occurred within the *B. compressus* Zone, to which they assigned a date of approximately 71.5 Ma. The age of the zone was revised by Obradovich (1993) to 73.35 $\pm$ 0.35 Ma using a date obtained from the Bearpaw Shale of Montana. Baadsgaard et al. (1993) used Rb/Sr, U/Pb and $^{40}Ar/^{39}Ar$ to determine a date for the contact of the *B. reesidei* Zone with the overlying *B. jenseni* Zone, using a bentonite from the Snakebite Member of the Bearpaw Formation in southwestern Saskatchewan (equivalent to the Manyberries Member in Alberta), yielding an average age of 72.4 Ma $\pm$ 0.3 Ma.

Most recently, Eberth and Deino (2005) reported the ages of two bentonites obtained with $^{40}Ar/^{39}Ar$ dating. Bentonite DPP-7 sampled 11 m above the base of the Bearpaw-Dinosaur Park contact (within the *B. compressus* Zone) yielded a date of 74.98 $\pm$ 0.24 Ma. A second date of 70.44 $\pm$ 0.17 Ma was obtained from bentonite HC-15 from the Drumheller Marine Tongue in the Horseshoe Canyon Formation, overlying the Number 10 Coal. This latter bentonite is significant as Lerbekmo and Braman (2002) identified the boundary between the 32r and 31n magnetozones in the Red Deer River valley 8 m below the Number 10 Coal bed. This transition was proposed as an indicator

of the Campanian-Maastrichtian boundary, occuring within the *B. baculus* Zone and fitting well with the date of 70.6 ± 0.2 Ma proposed by Ogg et al. (2004) for the boundary datum. Biozones and dates are summarized in Table 2.1.

Table 2.1: Summary of ammonoid biozones of the Western Interior during Bearpaw Time with measured radiometric dates.

ZONE Cobban (1993)	$^{40}Ar/^{39}Ar$ Date (Ma)	Bentonite Locality	Author
B. clinolobatus	69.42 ± 0.37	Red Bird Section, Niobrara WY	Obradovich (1993)
B. grandis			
B. baculus	70.44 ± 0.17	Horseshoe Canyon Fm, AB	Eberth & Deino (2005)
B. eliasi			
B. jenseni			
B. reesidei	72.5 ± 0.4	Bearpaw Fm, SK	Baadsgaard et al. (1993)
B. cuneatus			
B. compressus	73.35 ± 0.35	Bearpaw Fm, MT	Obradovich (1993)
B. compressus	74.98 ± 0.24	Bearpaw Formation, Dinosaur Provincial Park, AB	Eberth & Deino (2005)

2.2 STUDIED SECTIONS

2.2.3 Cypress Hills Section: RCA Thelma and Manyberries Locality

The Cypress Hills of southeastern Alberta and southwestern Saskatchewan are a unique feature of the Canadian plains that were not extensively subjected to the Quaternary glaciations of the surrounding prairie. The Cypress Hills rise to a maximum of 600 m in elevation over the surrounding terrain, preserving sediments that range from the Campanian to the Oligocene. The Bearpaw Formation in the Cypress Hills section is approximately 350 m in thickness and is found cropping out in horizontal surface exposures in creeks and coulees through out the area. The Cypress Hills were geologically mapped by Russell and Landes (1940) and Irish (1967) and the stratigraphy of the Bearpaw Formation within the section was proposed by Lines (1963). The composite section is illustrated in Figure 2.3.

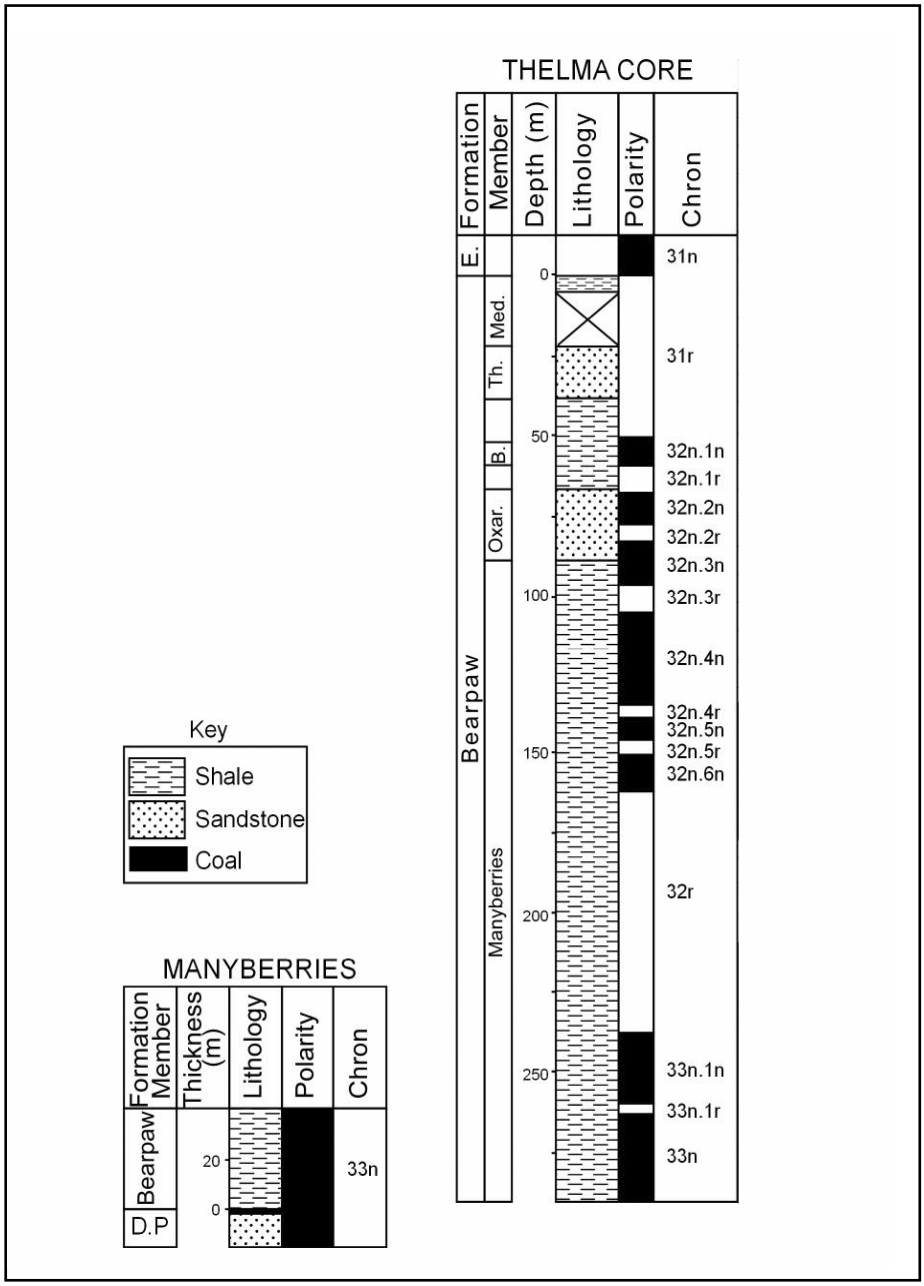


Figure 2.3: Stratigraphy of the Cypress Hills composite section, adapted from Lerbekmo and Braman (2002).
D.P.=Dinosaur Park Formation; Oxar.=Oxarart Member; B.=Belanger Member; Th.=Thelma Member; M.=Medicine Lodge Member

Lines (1963) divided the Bearpaw Formation into five members, with the lowest and thickest unit, the Manyberries Member, including all of the lower shale (clay and

silty/mudstone) beds. The remaining members (Oxarart, Belanger, Thelma and Medicine Lodge members) are centred on sandstone horizons, many of them described by Furnival (1941), with the additional attribution of adjacent intervening shale and mudstone units to some of them. Lomenda (1973) considered that the upper portion of the Bearpaw Formation was stratigraphically too complex and regionally varied to ascribe member-status to every non-shaly unit, considering it more suitable to treat the upper four units as part of an "Oxarart – Medicine Lodge Composite Member." However, for the purpose of this study the scheme proposed by Lines (1963) will be used.

Manyberries Member (Lines, 1963)

The Manyberries Member, named for the nearby town of Manyberries, Alberta, encompasses the lower portion of dark grey to grey-green silty clays and mudstones, interspersed with concretionary horizons and bentonite seams representative of the colloquial 'Bearpaw shale.' In the Cypress Hills, the Manyberries Member is 260 m in thickness and was subdivided by Furnival (1946) into seven lithozones, based on bentonites and concretionary lenses containing fauna representative of the *Baculites compressus* Zone. Caldwell et al. (1993) considered the Manyberries Member to span from the base of the *B. compressus* Zone to the lower part of *B. eliasi* Zone. This zonation was further refined by Tsujita (1995a) who recovered specimens of *B. compressus, B. cuneatus* and *B. reesidei* and considered the member's uppermost contact to be within the *B. jenseni* Zone. The member overlies the Dinosaur Park and Oldman Formations of the terrestrial Judith River Group, above the Lethbridge Coal Zone. It

extends from magnetozone 33n to near the top of the 32n.3n magnetochron (Lerbekmo and Braman, 2002).

Oxarart Member (Furnival, 1941)

The Oxarart Member gradationally overlies the Manyberries Member, consisting of greyish-brown weathering, upward coarsening marine and possibly non-marine sandstone. At its greatest extent the member is 20 m thick but thins to the east. Tsujita (1995a) associated the Oxarart Member (which he called the Black Eagle Member) with the *B. eliasi* Zone. The Oxarart Member extends from the uppermost portion of magnetochron 32n.3n to the middle of 32n.1r.

Belanger Member (Furnival, 1941)

The Belanger Member was defined by Furnival as the 6 m thick, buff weathering sandstone 7.5 m above the Oxarart Member that outcrops near Belanger Creek in the Cypress Hills. Lines (1963) extended the Belanger Member to also include the intervening clay and mudstone between the Belanger and Oxarart sandstones as well as the mudstone unit overlying the Belanger sandstone, immediately below the Thelma Member. The Belanger Member contains fossiliferous concretions bearing stratigraphically significant taxa, including the ammonoid *Baculites baculus* and foraminifera of the *Ammodiscus gyroidina* and *Haplophragmoides excavata* zones (Loranger and Gleddie, 1953; North and Caldwell, 1970). The member, including the mudstone units, extends from near the 32n.1r/32n.1n magnetochron transition to the lower third of the 31r magnetozone. It thus contains the Campanian-Maastrichtian

boundary within the Cypress Hills section. The Belanger Member grades into the marine sediments of the lowest part of the Horseshoe Canyon Formation at Castor to the north and into the marine and terrestrial sediments of the St. Mary River Formation to the west (Lomenda in Glass, 1997, p. 128).

Thelma Member (Furnival, 1946)

The Thelma Member consists of greenish- to bluish-grey fine sandstone, 12 m in thickness where it crops out at the type locality at Thelma Creek and is capped with a seam of lignite 10 to 75 cm thick. The member transitionally overlies the dark grey shale ascribed by Lines to the upper part of the Belanger Member. The Thelma Member is completely contained within the 31r magnetozone and lies in the upper half of the *Ammodiscus gyroidina* and *Haplophragmoides excavata* foraminiferal zones (Loranger and Gleddie, 1953; North and Caldwell, 1970). The Thelma Member has been correlated with sediments of the Horseshoe Canyon Formation below the Drumheller Member in the Red Deer River valley and at Castor. It also undergoes a shift in facies to the west, grading into the marine and terrestrial sediments of the St. Mary River Formation (Lomenda in Glass, 1997, p. 1181).

Medicine Lodge Member (Lines, 1963)

The Medicine Lodge Member was proposed by Lines as the name "for those dark grey, blocky shales that lie above the Thelma Member and below the Eastend Formation…which are well exposed…along Medicine Lodge Coulee" (Lines, 1963 p. 216). These silty clay and mudstones are 25 m thick at the type locality, sharply overlying

the Thelma Member and transitionally underlying the non-marine Eastend Formation, becoming increasingly arenaceous. The member appears to occur completely within the *Baculites grandis* Zone (Tsujita, 1995a, figure 3.11) and straddles the upper half of the 31r magnetozone and the lowest part of the 31n magnetozone. It is correlated with the Drumheller Marine Tongue of the Horseshoe Canyon Formation.

2.2.2 Castor Section

The Bearpaw Formation in the Castor-Hand Hills district of Alberta is 122 m thick, consisting of alternating shale and sandstone units, illustrated in Figure 2.4. Lines (1963) measured outcrops along the Battle River and Paintearth Creek, informally recognizing two members: the Young Creek Member and the Paintearth Member. Lines reported a bed of chert pebbles separating the units, suggesting an unconformity between them. However, the lack of formally stated type localities and the difficulty in correlating the members in the subsurface make these distinctions questionable.

Given and Wall (1971) proposed a more informal, though more workable, scheme for the Castor area in their report on the microfauna recovered from the Research Council of Alberta's Castor borehole: lower, middle and upper shale units, separated by two sandstones named in descending order the "First" and "Second Castor Sandstones". The "lower shale unit" consists of the grey to grey-green shale and mudstones typical of the Bearpaw Formation overlying the Dinosaur Park Formation with a clearly defined basal contact within the borehole. Several unnamed minor glauconitic sandstones were reported in the unit. The lower shale is synonymous with all of Lines' 'Young Creek Member' and possibly the lowest part of his 'Paintearth Member' although no chert pebbles were reported.

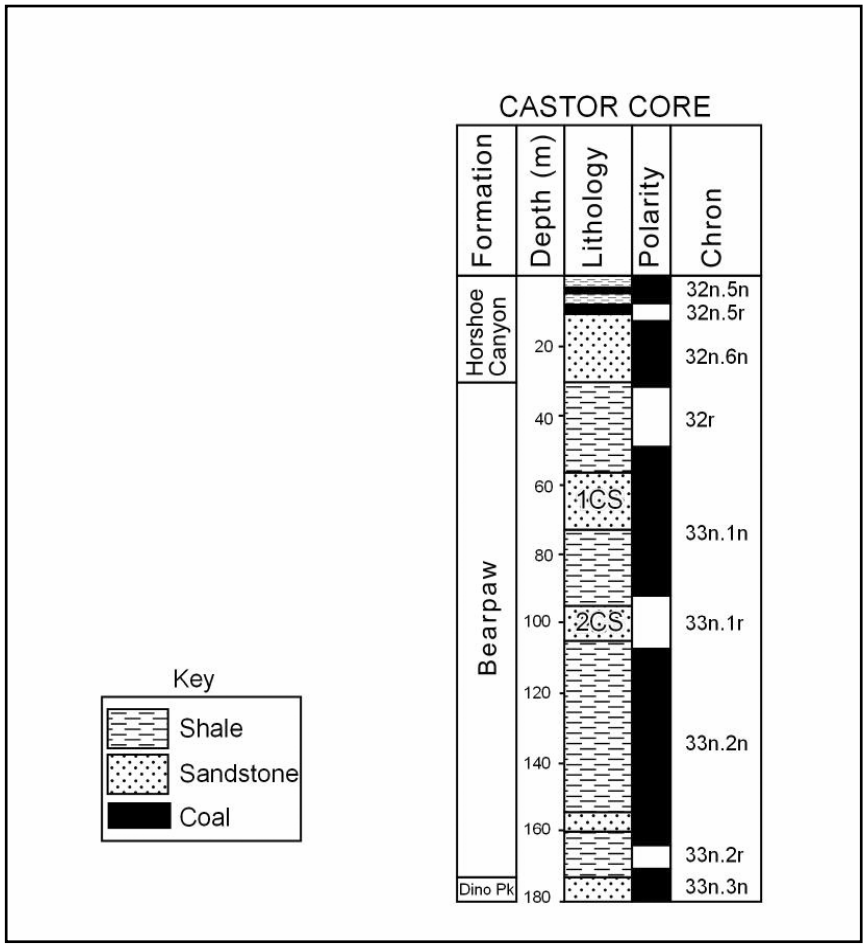


Figure 2.4: Stratigraphy of the RCA Castor Core, adapted from Lerbekmo et al. (2003). "1CS" and "2CS" are the First and Second Castor sandstones, respectively. Given and Wall's "upper shale unit" is located above the 1CS, the "middle shale unit" between the 1CS and 2CS, and the "lower shale unit" below the 2CS (Given and Wall, 1971).

Conformably overlying the lower shale is the Second Castor Sandstone, a 10 m thick bed of greyish-green glauconitic and bentonitic medium-grained sandstone that Given and Wall considered to be the equivalent of the "Bulwark Sandstone" within Lines' 'Paintearth Member.' (Given and Wall, 1971, p. 506). This sandstone is in turn overlain by the 'middle shale unit' approximately 22 m in thickness. The First Castor Sandstone is 18 m in thickness and can be correlated with unnamed sandstones within the

'Paintearth Member' above the Bulwark Sandstone. Finally, the upper shale unit extends to the top of the Castor core, of which the lowest 26 m is ascribed to the Bearpaw Formation. The remaining shale represents a marginal marine facies within the lowest part of the Horseshoe Canyon Formation.

The Castor section of the Bearpaw Formation represents the northwestern margin of an embayment of the Bearpaw Sea (Figure 2.1), and thus the sea receded from the area with the onset of regression earlier than in the Cypress Hills. The entire Castor section is correlated with the Manyberries Member, encompassed by magnetozones 33n and 32r, and ranges from the *Baculites compressus* to *B. jenseni* ammonoid zones (Lerbekmo et al., 2003).

3.0 PREVIOUS RESEARCH

3.1 PALAEONTOLOGICAL RESEARCH IN THE BEARPAW FORMATION

3.1.1 Macropalaeontology

Much of the palaeontological research carried out in the Bearpaw Formation has been concerned with biostratigraphic characterization of strata, the study of palaeoenvironmental conditions within the Bearpaw Sea (primarily in relation to environmental conditions and palaeoecology of the adjacent land mass) and the macrofauna that inhabited the seaway. Ward et al. (1982) reported that at least 54 species of marine invertebrates have been recovered from Bearpaw strata in Alberta, including ammonoid and baculitid cephalopods, bivalves and gastropods. Tsujita and Westermann (1998) also reported the occurrence of lobsters and other decapod crustaceans in concretions from the formation. In addition to their use in biostratigraphic studies, molluscs have also been used in stable isotope studies by a number of workers to elucidate palaeoceanographic conditions within the Western Interior Seaway (Forester et al., 1977; Brass et al., 1982; Kyser et al., 1993; Cadrin et al., 1995; Cochran, et al. 2001; He et al., 2005).

Vertebrate macrofossils have also been the subject of several investigations from strata in Alberta and Saskatchewan. Vertebrates recovered from the Bearpaw Formation, as well as adjacent strata, have included mosasaurid and plesiosaurid marine reptiles, hesperornithoform birds, turtles, sharks and fishes (Nicholls and Russell, 1990; Nicholls et al., 1990; Holmes et al., 1999; Brinkman et al., 2005; Sato, 2005). Nicholls et al (1990)

reported the recovery of dinoflagellate cysts from inside the carapace of one of the turtles included in their study.

3.1.2 Micropalaeontology

Microfossils have also been extensively studied, particularly foraminifera, radiolaria and diatoms. North and Caldwell (1970, 1975; Caldwell et al., 1978) developed a zonation scheme using foraminifera for the Cretaceous of the interior plains, based initially on material from borehole core samples and outcrops from Saskatchewan. The Bearpaw Formation is contained within their Foraminiferal Zones XI to XVI, with the Manyberries Member ranging about Zones XI to XV, with remainder of the Cypress Hills section contained with Zone XVI. Preliminary work was also done on the development of a biozonation scheme based on diatoms and radiolaria (Given and Wall, 1971; Wall, 1975).

3.2 PREVIOUS PALYNOLOGICAL STUDIES

3.2.1 Terrestrial Palynology

The majority of palynological studies of the palynoflora of the plains have dealt with terrestrial palynomorphs: spores, megaspores and pollen. These studies have been primarily concerned with the continental strata underlying and above the Bearpaw marine interval, but reports have often included terrestrial palynomorphs that were washed into the Bearpaw Sea. In addition to the magneto-palynostratigraphies of Lerbekmo and Braman (Lerbekmo and Braman, 2002; Lerbekmo et al., 2003), terrestrial studies have also been instrumental in establishing the extent and rate of the flooding and retreat of the Bearpaw Sea.

Braman and Koppelhus (2005) reported an extremely rich diversity of palynomorphs from the Dinosaur Park Formation, including 500 species of terrestrial palynomorphs, not including megaspores, fungal spores and dinocysts. The latter were recovered from marine sediments at the top of the Dinosaur Park Formation in the Lethbridge Coal Zone, indicating that there were several transitory episodes of marine flooding prior to the full onset of marine conditions in the Red Deer River valley. Palynological studies in the Horseshoe Canyon Formation have also been invaluable in tracking the regression of the Bearpaw cyclothem in south-central Alberta (i.e. Srivastava, 1970).

Wall et al. (1971) reported three assemblages of foraminifera and megaspores recovered from the CPOG Strathmore borehole east of Calgary. The Bearpaw Formation was contained within their "inner-neritic assemblage" that contained a varied foraminiferan fauna, poorly preserved megaspores and thin-walled, cavate peridinoid dinoflagellates.

Norris et al. (1975) divided the sediments of Albian to Campanian age within the Western Interior into nine distinct suites of terrestrial palynomorphs, with the Bearpaw Formation within the uppermost *Cranwellia* suite. Nichols and Sweet (1993) described assemblages of terrestrial palynomorphs along a north – south transect from the Yukon to New Mexico, with the composition of flora varying as a function of latitude in addition to changes in succession over geological time. They found that much of the Late Cretaceous palynoflora of the Western Interior Basin was characterized by species of the triprojectate genus *Aquilapollenites*, with the Bearpaw Formation placed stratigraphically within their *Aquilapollenites quadrilobus* Zone (Nichols et al., 1982; Nichols, 1994). It was also

proposed that the first occurrences of the genera *Wodehouseia* or *Kurtzipites* were a potential indicator of the C-M Boundary (which would be equivalent to *Baculites jenseni* time).

3.2.2 Previous dinoflagellate studies in the Bearpaw Formation

The recovery of dinocysts and acritarchs from the Bearpaw Formation was first reported by Harland (1973) from Alberta and later from Montana (Harland, 1977). The Alberta assemblage included 53 species of dinoflagellate cysts and six acritarchs. Of particular interest were the report of several previously undescribed taxa, including *Spinidinium clavus*, *"Diconodinium" (*now *Laciniadinium) firmum* and "*Lejeunia parva" (*now *Palaeoperidinium parvum)*. Harland reported that the assemblage was dominated by species now attributed to the peridinoid genera *Chatangiella, Laciniadinium* and *Palaeoperidinium*, with notable occurrences of the gonyaulacoid genera *Oligosphaeridium, Hystrichosphaeridium, Cyclonephelium* (now *Circulodinium*) and *Odontochitina.*

Harland collected samples from 14 localities – seven from outcrops along the St. Mary's River south of Lethbridge and seven from the Cypress Hills south of Elkwater, Alberta and were reported to range from *Baculites compressus* to *B. baculus* time (Harland, 1973 p. 666). Most of the samples from the Cypress Hills localities were collected from the Manyberries Member, with one sample collected from the Belanger Member (representing the sole sample collected within the *B. baculus* Zone). No samples were collected from the intervening Oxarart Member or the overlying Thelma and Medicine Lodge members. The Cypress Hills material was subsequently supplemented with samples from the RCA Thelma core, although only from the middle third of the

Manyberries Member (Harland, 1973 fig. 13). Three informal assemblage zones were recognized, all within the Manyberries Member, with a varied mix of peridinoid and gonyaulacoid cyst-types.

The Montana assemblage reported in Harland (1977) is considered to be younger than the Albertan assemblage reported in Harland (1973), and was found to be a much sparser, lower diversity flora dominated almost entirely by peridinoid cysts. This was attributed to a shallowing of the Bearpaw Sea and an increase in terrestrial influx (Harland, 1977, p. 190). Of particular note in the study was the observation of a definite floral change within the succession, with 'Campanian taxa' including *Odontochitina operculata* and "*Cyclonephelium" (Circulodinium) distinctum* disappearing prior to the appearance of *Cerodinium diebelii, Phelodinium golzowense* and *"Senegalinium" (Phelodinium) magnificum*, taxa Harland considered to be indicators of the Maastrichtian.

In his palynostratigraphy of the interior plains of Western Canada, Harker (1977, Harker et al. 1990) developed eight parazones using dinoflagellate and acritarch cysts in a composite stratigraphic column ranging from the late Santonian to the latest Campanian and included the Bearpaw Formation from surface and subsurface localities of Saskatchewan and Alberta. These parazones were correlated with ammonite and foraminifera biozones for the region. This zonation originally reached into the earliest Maastrichtian (Harker, 1977), but subsequent work suggested that the possibly Maastrichtian samples were in fact more likely to be latest Campanian in age based on their stratigraphic position (Sarjeant, pers. comm., 2000; Kurita and McIntyre, 1994).

The strata used in the present study span Harker's M7 and M8 parazones. Parazone M7 was found to correlate with the basal Bearpaw contact with the Dinosaur

Park Formation at Lethbridge, ranging from roughly the base of the *Didymoceras cheyennense* to the top of the *Baculites compressus* zones (Harker, 1977 p. 484), thus correlating with the lower two thirds of the Manyberries Member in the Cypress Hills section and to the top of the Second Castor Sandstone in the Castor section (this study). Important dinocysts that Harker identified in M7 include the peridinoid cysts *Chatangiella spectabilis*, *Laciniadinium firmum* and *L. biconiculum* and the gonyaulacacean *"Cyclonephelium" (Circulodinium) distinctum*. The peridinoid *Spinidinium clavus* was reported as a minor constituent in Harker's Saskatchewan samples and a decrease in abundance was observed in several species from an acme at the parazone's base, including *Palambages morulosa, Palaeoperidinium cretaceum, Palaeoperidinium pyrophorum, Alterbidium acutulum* and *Alterbidium minor* and the acritarchs *Micrhystridium harlandii* and *Fromea chytra* (formerly of the genus *Palaeostomocystis*). Harker attributed this decrease to "an influx of coarser clastics culminating in the Ardkenneth Sand" in Saskatchewan (*ibid.*). Species that Harker reported to not range above Parazone M7 included *Chatangiella decorosa* and "*Cleistosphaeridium" (Downiesphaeridium) armatum*.

Harker (1977) initially attributed Parazone M8 as being of latest Campanian and possibly earliest Maastrichtian age, particularly due to the occurrence of *"Ceratiopsis"* (now *Cerodinium*) *diebelii, C. pannuceum* and *Phelodinium magnificum.* Other prominent dinocyst taxa noted, particularly at the parazone's base, included the peridinoids *Alterbidium acutulum, Laciniadinium biconiculum* and *L. firmum, Palaeoperdinium cretaceum* and *P. pyrophorum, Palambages morulosa* and the gonyaulacoid "*Cyclonephelium" (Circulodinium) distinctum* (p. 486). However, the

parazone's correlation between the *Baculites cuneatus* and *B. reesidei* zones, coupled with lack of other evidence, led Harker to limit Parazone M8 to the uppermost Campanian.

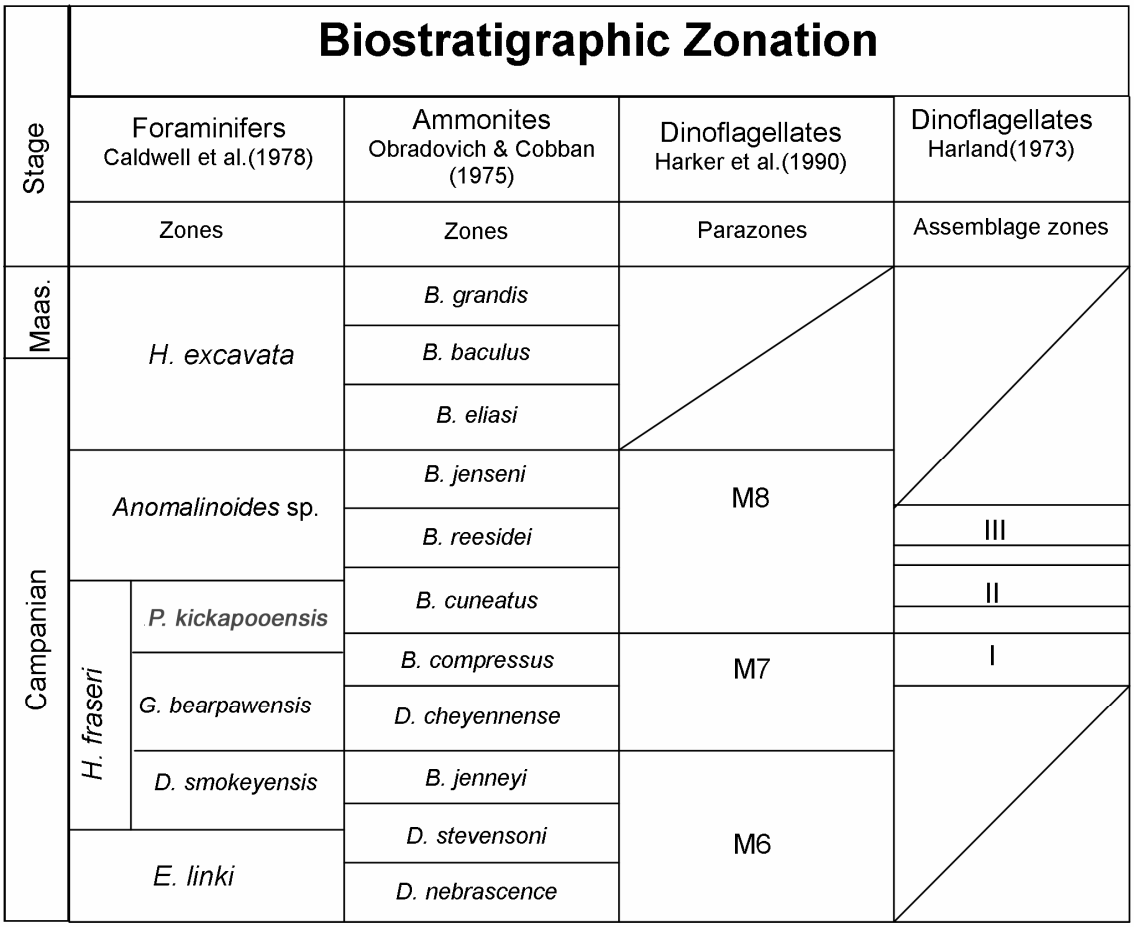


Figure 3.1: Correlation of biostratigraphic zonations of the Bearpaw Formation using foraminifera, ammonoids, and dinoflagellates (adapted from Kurita and McIntyre, 1994).

Besides the reports of Harland (1973) and Harker (1977; Harker et al., 1990), there have been few reports of dinoflagellates from the Bearpaw Formation or other contemporary strata in the western interior plains. Kurita and MacIntyre (1994) reported recovering dinoflagellate assemblages from the Bearpaw Formation near Calgary,

confirming that the Bearpaw Sea reached at least as far as the Rocky Mountain foothills during the late Campanian. Wall and Sweet (1975) and McIntyre et al. (1984) included preliminary lists of dinoflagellate flora. Wall and Singh (1975) reported recovery of a 'Bearpaw flora' from the Buffalo Head Hills of north-central Alberta, thereby providing evidence of a connection between the Arctic and the Western Interior Seaway during the Santonian and Campanian.

3.2.3 Studies of other Campanian – Maastrichtian Assemblages in North America

Arctic Canada

McIntyre (1974, 1975), Doerenkamp et al. (1976), Ioannides (1986) and Núñez-Betelu and Hills (1992, 1994; Núñez-Betelu et al., 1994) described assemblages recovered from Campanian and Maastrichtian strata in the Canadian Arctic. Peridinoid species, particularly cavate cysts of the genus *Chatangiella,* dominate the assemblages, along with *Laciniadinium arcticum, L. biconiculum, L. firmum, Spinidinium clavum, Palaeoperidinium cretaceum* and *P. pyrophorum.* Definite changes in assemblage composition were also noted over the C-M boundary interval, with Campanian taxa such as species of *Odontochitina* giving way to Maastrichtian species such as *Cerodinium diebelii.*

United States

In addition to the Bearpaw strata of Alberta and Saskatchewan, Harker (1977; Harker et al., 1990) reported dinoflagellate assemblages from coeval strata of the Pierre Shale and Niobrara Formation of Red Bird, Wyoming and the Taylor Marl of the Texas

Gulf Coast. The Red Bird assemblage was found to conform well to parazones M6 and the upper portion of parazone M8 in the Saskatchewan localities, being dominated by peridinoid taxa and including species such as *Laciniadinium biconiculum, L. firmum*, *Palaeoperidinium cretaceum, Cerodinium pannuceum, Spinidinium clavus, Cyclonephelium distinctum, Palambages morulosa* and *Alterbidinium acutulum.* Parazone M7 and the base of parazone M8 (roughly an interval equivalent to the *Didymoceras cheyenennse* to *Baculites cuneatus* zones) were found not to be present due to an unconformity.

Harker (1977) found that the assemblage he recovered from the Texas Gulf Coast did not compare well with the northern localities, being dominated by chorate gonyaulacoid cysts (p. 495). In addition to being older, the composition of the Texas assemblage no doubt reflects warmer Tethyan waters. Zaitzeff and Cross (1966) and Heine (1991) reported on other assemblages from Texas – the former from the Navarro Formation of central Texas and the latter from the northeast of the state. Zaitzeff and Cross considered their assemblage to be primarily Maastrichtian in age and divided it into three zones. However, the lowermost zone, Zone A, included specimens of *Odontochitina costata* as well as taxa that had not "been previously recorded from rocks as young as the Maastrichtian" (Zaitzeff and Cross, 1966, p. 353). This suggests that at least this zone is in fact Campanian. This conclusion was supported by Heine (1991), who proposed that the Campanian-Maastrichtian boundary in Texas could be characterized by the last occurrences of *Senoniasphaera protrusa* and *S. rotundata.* Paradoxically, however, Heine also proposed that species of *Odontochitina* ranged into Maastrichtian strata, while *"Ceratiopsis diebelii"* (*Cerodinium diebelii*) was reported from Campanian sediments.

4.0 MATERIALS AND METHODS

4.1 MATERIALS

The samples used in this study are from two cores from boreholes drilled by the Research Council of Alberta near Castor (RCA Castor) and near Thelma Creek in the Cypress of Hills of Alberta (RCA Thelma 66-1), respectively, and one set of surface collections made near Manyberries, Alberta. The Castor material consists of 56 samples collected by Dr. A.R. Sweet and prepared by the Geological Survey of Canada, Calgary for the author. The Thelma sample set comprises 150 splits of unprocessed material collected by the author from samples taken by Dr. J.H. Wall from the Thelma core at intervals along its entirety. This material was supplemented by 18 prepared slides from the collections of the Royal Tyrrell Museum of Palaeontology of the upper 76 m of the core as there was either insufficient material to split or the material had been previously consumed. Finally, 31 surface samples were collected from outcrop southeast of the town of Manyberries, Alberta. Localities are illustrated in Figure 4.1.

4.1.1 RCA Castor Core 13-34-37-13W4

The RCA Castor corehole was drilled in 1967 by the Research Council of Alberta to a depth of 181.7 m. The core spans the lower part of the Horseshoe Canyon Formation, the entire Bearpaw Formation and the basal contact with the underlying Dinosaur Park Formation. Lithological logging of the core was performed by J.H. Wall in 1971. The core consists of an alternating series of shales and sandstones (Figure 4.2).

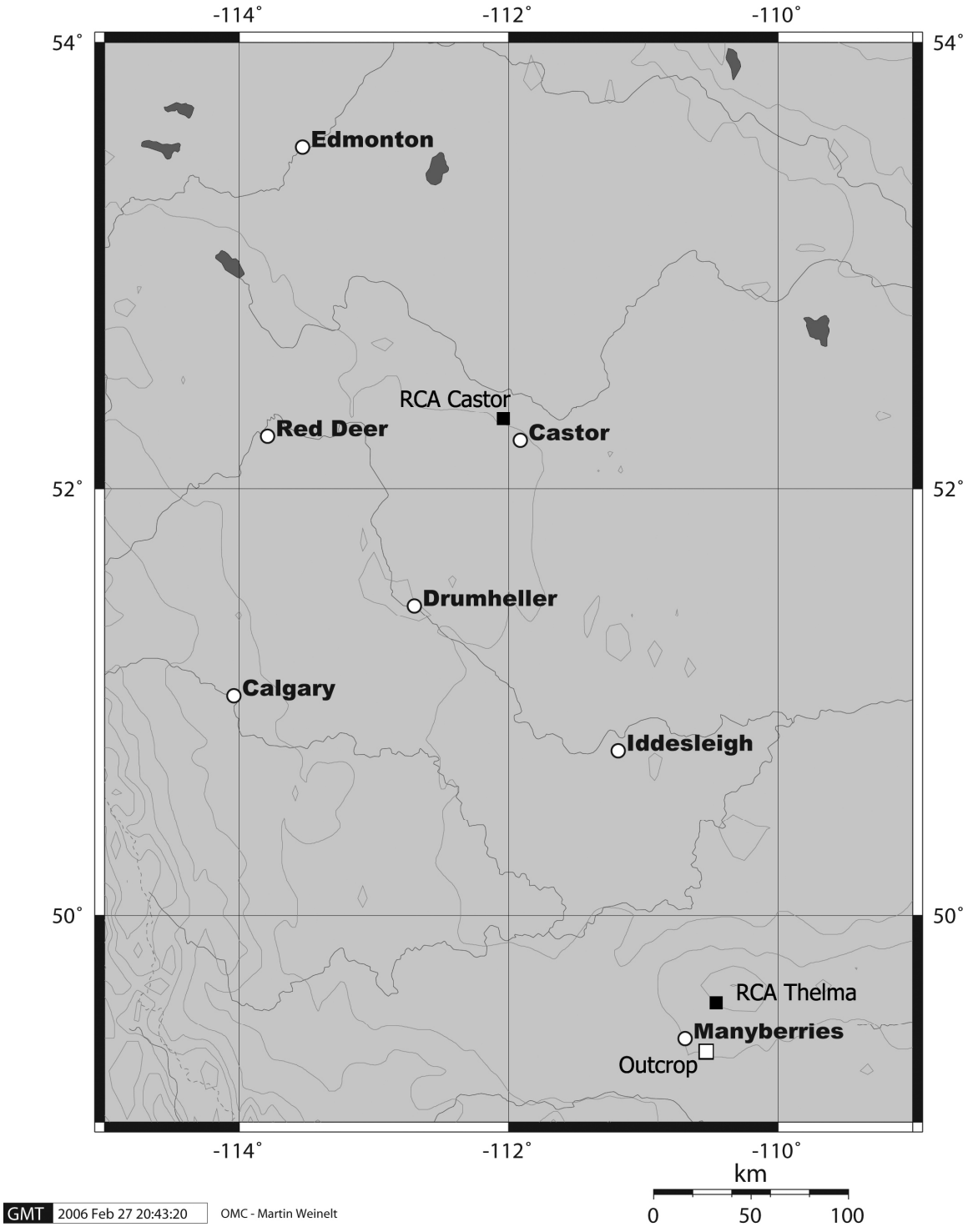


Figure 4.1: Map of southeastern Alberta showing localities sampled in this study. Key: ■= subsurface core; □ = outcrop.

Given and Wall (1971) reported these latter units in descending order as the first and second Castor sandstones, respectively. The "upper shale unit" in the Horseshoe Canyon Formation overlies the First Castor Sandstone, and is indicative of one of several marine pulses within the lower part of the formation. The "middle shale unit", lying between the first and second sandstones and the "lower shale unit" beneath the Second Castor Sandstone are within the Bearpaw Formation. Two smaller, unnamed sandstone units occur within the lower shale. The Bearpaw Formation has a clearly defined contact with the underlying Dinosaur Park Formation at 174 m depth.

The sands within the core are grey to grey-green, medium-grained and are commonly glauconitic and bentonitic. The shale units are very representative of the colloquial 'Bearpaw Shale', consisting of medium- to dark-grey or green-grey mud and siltstones, with varying amounts of lamination, shell fragments and pyrite stringers. Lithological descriptions of the samples studied are listed in Appendix 1.

The samples used in this study were originally collected by Dr. A.R. Sweet for palynological processing to complement the samples collected for palaeomagnetic analysis by Dr. J.F. Lerbekmo as reported in Lerbekmo et al. (2003). Harland (1973) reported dinoflagellates from the Castor core, comparing them to surface samples he had studied.

4.1.2 RCA Thelma Core (66-1) 14-31-6-2W4

The RCA Thelma core was spudded in 1969 as a water testhole by the Research Council of Alberta east of Thelma Creek on the southern flank of the Cypress Hills. The core extends 301 m, from low in the Eastend Formation approximately 35 m above the Bearpaw contact, through almost the entire vertical extent of the Bearpaw Formation in

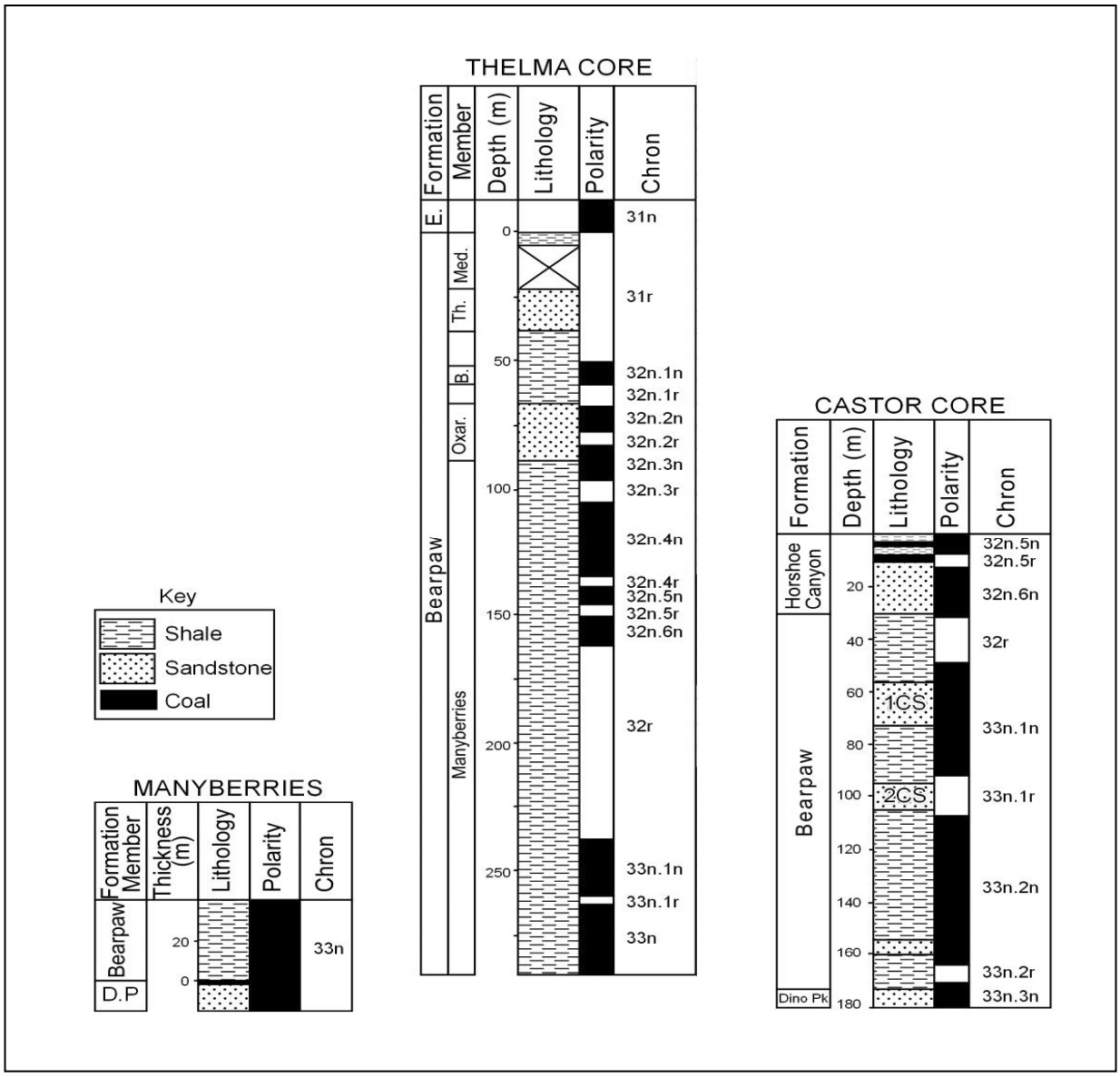


Figure 4.2: Magnetostratigraphic and lithological correlation of the study localities. Manyberries outcrop and Thelma core adapted from Lerbekmo and Braman (2002); Castor core adapted from Lerbekmo et al. (2003).

the Cypress Hills section, save for the lowermost 30 – 35 m of the Manyberries Member. The core was logged and originally sampled for micropalaeontology by J.H. Wall and subsequently sampled for magnetostratigraphy and terrestrial palynostratigraphy, the results of the latter study published in Lerbekmo and Braman (2002).

All five members of the Bearpaw Formation in Alberta are represented in the Thelma core (Figure 4.2). The uppermost shale unit, the Medicine Lodge Member, was found by Lerbekmo and Braman (2002) to be highly bentonitic and was unrecoverable from -5 m to the top of the sandstone Thelma Member. The Belanger Member within the core consists of an interbedded grey-green shale and glauconitic mudstone with shell fragments, and is considered to be equivalent to the outcrop of the Belanger Member in the Cypress Hills of Saskatchewan as described by Furnival (1946). The underlying sandstone member is considered to be the equivalent of the Oxarart Member in Saskatchewan, although Russell (1948) believed it to be older than the Oxarart sandstone and proposed that the Alberta sandstone be instead called the "Black Eagle Member," a name which has been validly published in the *Lexicon of Canadian Stratigraphy*, although the citation states that the name is "rarely recognized by modern workers" (Lomenda in Glass, 1990, p. 116). The Manyberries Member makes up approximately the bottom two-thirds of the core. It is predominantly composed of 'Bearpaw shale' with recovery of the core failing at the top of a "lower bentonite zone".

Splits of unprocessed sample materials were made from the residuum stored at the Royal Tyrrell Museum of Palaeontology in Drumheller. Samples had been originally taken at approximately 1.0 – 2.5 m intervals, or one sample per core box, save for spot samples taken at locations of interest due to changes in lithology. One hundred fifty splits

were made; encompassing the core from 104 to 300 m, of which 75 were selected for palynological processing (samples GMUS 4201 to 4358). Insufficient material remained of the core above 104 m, and slides prepared by GSC Calgary from material collected between 13.4 to 76.2 m were loaned to the author by Dr. Braman (RTMP DB89-1-01 to DB89-1-18), which had been previously used in Lerbekmo and Braman (2002) to assess terrestrial palynomorphs. The intervening gap, from 76.3 to 104 m, was not recovered. Detailed lithologic descriptions are listed in Appendix A.

4.1.3 Manyberries 7-35-4-5W4 to 10-23-4-5W4

Since the lower 35 m of the Bearpaw Formation was not recovered in the Thelma core, surface samples were collected from an exposed section 10 km southeast of Manyberries, Alberta where the top of the continental Dinosaur Park Formation crops out and extends through the Lethbridge Coal Zone to the top of the unrecovered lower bentonite zone. Thirty-one samples were collected from below the weathered surface of the section at intervals along a transect perpendicular to the outcrop. Sample collection began below the Lethbridge Coal Zone in terrestrial sediments of the Dinosaur Park Formation (consisting of organic-rich, brown to olive-grey mud and siltstone with some sandstone lenses), through the Lethbridge Coal and into the Bearpaw shale (see Figure 4.2). The section was measured using a 1.5 m ‘pogo stick’ with start and stop locations measured by GPS (UTM coordinates based on NAD 83 datum). Due to the very gradual slope, the 90.6 m of vertical outcrop extended a horizontal distance of approximately 2 km.

Of the 31 samples collected, the uppermost 10 were selected for palynological processing at the University of Saskatchewan Palynology Laboratory based on lithology as being the bottom section of the Manyberries Member and are described in Appendix A.

4.2 PALYNOLOGICAL PROCESSING

Palynomorphs were extracted from samples using standard palynological acid disintegration techniques (Barss and Williams, 1973; Doher, 1980). Samples were processed in two different laboratories. Samples collected by the author as splits from the Thelma core and surface collections from the Manyberries outcrop locality were processed in the Palynological Laboratory, Department of Geological Sciences, University of Saskatchewan. Prepared slides from the Castor core and the upper portion of the Thelma core were prepared at the Geological Survey of Canada in Calgary.

The specific protocol followed in the University of Saskatchewan Palynology Laboratory involved pulverizing 5 to 10 grams of sample that had been previously washed and dried using a clean mortar and pestle. The crushed material was then transferred to 1.0 litre plastic digestion jars, covered in distilled/demineralized water and then treated with 10% HCl, with the occasional addition of 18% HCl, depending on the samples' reactivity, to dissolve carbonates. After dilution to neutrality using demineralised water and decanting of supernatant liquid, 30% HF was added to dissolve silicates and again diluted to neutrality with demineralized water. Cold oxidation using Schulze solution ($KClO_3$ crystals dissolved in concentrated HNO_3) or 10% HNO_3 was carried out on approximately 75 ml of digested sediment in 150 ml centrifuge tubes for 2 to 5 minutes, depending on the amounts of detrital organic matter present. Excess

residuum was stored in sealed vials under phenol. After washing with 10 ml of 5% NH_4OH followed by washing with distilled water and centrifuging, an aliquot of residue solution was transferred to 15 ml centrifuge tubes under 10% HCl. Heavy liquid separation was performed using 5 ml of concentrated $ZnCl_2$ solution (specific gravity 2.0), with the floating fraction retained, washed in distilled water and sieved through a clean 15 µm sieve, using 10% HCl as needed to encourage any clumped precipitate through the filter. After staining with saffranin-O and final centrifuging, residue was strew-mounted by pipette on 22 mm by 22 mm cover slips. Once dried by evaporation, cover slips were mounted to microscope slides using Canada balsam and cured in an oven. Where possible, up to five slides of a given interval were prepared. Excess stained residue was also stored under phenol in sealed glass vials.

The palynological processing method used by the Geological Survey of Canada differed principally in the concentration of acids used for the initial digestion of matrix, in the use of ZnBr for heavy liquid separation (S.G. 2.0) and in the use of 150, 20 and 10 µm sieves. Three slides were prepared of each sample, one each of the unsieved, +20 µm and -20 µm fractions. These were strew-mounted on 22 mm by 44 mm coverslips and adhered to slides using bioplastic.

4.3 DATA COLLECTION

4.3.1 Microscopy

Scans, counts and microphotography were conducted on a Zeiss photomicroscope (serial number 64391) fitted with optovar and phase contrast, originally purchased by W.A.S. Sarjeant in the Department of Geological Sciences, University of Saskatchewan.

Scans were first made of the slides at 2 and 5 mm intervals to ascertain the nature of the assemblages and to identify, measure and figure the taxa found. Occurrences of species were then charted.

4.3.2 Specimen Counts

Several workers have approached the issue of the specimen count required to assure a reasonable sample size has been collected, with the resulting number varying between 200 specimens of dinocysts (Harker, 1977) and 500 specimens of all palynomorphs in a study (Ioannides, 1986; Sluijs et al., 2005). In his treatise on foraminifera ecology, Phleger (1960) proposed that 300 specimens was a practical number with which to determine a representative sample size; a number now commonly used by many micropalaeontologists (Revets, 2004).

It became apparent early in the scanning phase of this study that it would be impractical considering the number of samples, if not impossible given the material available, to obtain counts exceeding even 100 dinocysts in most samples. It was therefore decided that a method similar to that used by Ioannides (1986) and others would be followed, in which all palynomorphs encountered would be counted up to a target sample size. Thus slides were counted to a target number of 350 palynomorphs (with counts yielding between 129 and 450 specimens). Where possible, dinocysts and acritarchs were counted to the species level, with terrestrial palynomorphs grouped as ‘Spores and Pollen’ (including monolete and trilete pollen), ‘Bisachates’, and specimens of the genus *Aquilapollenites*. Fungal spores and algal cells were likewise placed in their own categories.

Where possible, counts were made of samples at 8 to 10 m intervals throughout the Thelma and Castor cores, nothwithstanding regions of non-recovery. Slides of

Thelma material prepared at the University of Saskatchewan were scanned using vertical transects at 1 mm intervals on two or three slides until a minimum target number of 350 palynomorphs (dinocysts and terrestrial spores and pollen) was reached. Only slides of the +20 μm fraction prepared by GSC Calgary (or the unsieved fraction, if there was insufficient processed material) were counted at 1 to 2 mm intervals to the target number. In both cases, the remainder of the slide was then scanned for any biostratigraphically significant or new taxa.

The counting procedure for the samples collected at the Manyberries locality followed that used for the Thelma slides prepared at the University of Saskatchewan. Counts were made at an average sampling interval of 10 m.

5.0 SYSTEMATIC PALAEONTOLOGY

5.1 DINOFLAGELLATE SYSTEMATICS

Supergeneric classification of dinoflagellates follows the scheme laid out by Fensome et al. (1996) and the database DINOFLAJ based on the same scheme (Fensome et al., 1998). Classification at the levels of genus and species follows the systematics of Fensome and Williams (2004) in most cases (exceptions are noted below). Taxonomic synonyms listed include the original description and notable emendations. The 'Occurrence' section includes previously reported occurrence in the Bearpaw Formation or other Campanian-Maastrichtian strata in North America. Measurements are given in the format 'minimum (mean) maximum' in μm. In the case of chorate/proximochorate cysts, the cyst measurement is for the autocyst only.

Division DINOFLAGELLATA (Bütschli) Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Subdivision DINOKARYOTA Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Class DINOPHYCEAE Pascher 1914

Subclass GYMNODINIPHYCIDAE Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Order GYMNODINIALES Apstein 1909

Suborder PTYCHODISCALES Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Family PTYCHODISCACEAE Willey and Hickson 1909

Subfamily DINOGYMNIOIDEAE (Sarjeant and Downie)

Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Genus *Dinogymnium* Evitt, Clarke and Verdier 1967

Dinogymnium acuminatum Evitt, Clarke and Verdier 1967

Plate 1, Figure 1

1967 *Dinogymnium acuminatum* Evitt, Clarke and Verdier, p1.l, figs.21-23; p1.2, fig.5; text-figs. 16-18.

Remarks: The recovered specimens conform well to the type material, including in their notable variation in size. The hypocysts of several specimens were quite rounded at the antapex, a trait noted by Cookson and Eisenack (1960) and Harker et al. (1990) and illustrated by McIntyre (1974) as *Dinogymnium* cf. *kazachstanum.* Lentin and Vozzhennikova (1990) included *Dinogymnium kazachstanum* as a junior taxonomic synonym of this species.

Dimensions: Cyst: length: 24 (50) 71 μm; width: 24 (30) 40 μm

Measured: 6

Occurrences: Antonescu et al. (2001) identified the last occurrence of this species as one of the dinocyst biosignals of the C-M boundary at Tercis les Bains. The recovery of the species was also limited to pre-Maastrichtian strata in this study, conforming to their interpretation.

In the Cypress Hills, the species was limited to the Manyberries Member from chrons 33n to 32n.3r. The species was recovered from the Castor core in two zones, from subchrons 33n.2r to 33n.2n and

subchrons 32r through 32n.6n.

D. acuminatum was recovered by McIntyre (1974) from the Northwest Territories (as *D.* cf. *kazachstanum*), Wall and Singh (1975) from the Buffalo Head Hills of Alberta, and by Harker (1977) and Harker et al. (1990) from the Bearpaw, Niobrara and Pierre formations of the Western Interior. Williams et al. (1993) published a chronostratigraphic range for all *Dinogymnium* species of 90 to 66.5 Ma.

Figured: GSC 401356 010/103

Dinogymnium digitus (Deflandre) Evitt, Clarke and Verdier 1967

Plate 1, Figure 2

1935 *Gymnodinium digitus* Deflandre, p. 225-226, text-figs.7-8.

1936 *Gymnodinium digitus* Deflandre, p. 166-167, p1.2, figs 4-5.

1967 *Dinogymnium digitus* (Deflandre) Evitt, Clarke and Verdier, p. 18-19.

Remarks: The recovered specimens closely resemble the illustrated holotype. The cysts are more elongate than other species of the genus, with epicysts and hypocysts nearly equal in length and with much lower relief surface ornamentation.

Dimensions: Cyst: length: 46 (60) 74 µm; width: 30 (35) 33 µm

Measured: 4

Occurrences: This species was recovered in three samples from the Cypress Hills section: from the base and near the middle of the Manyberries Member (chron 33n) and from the base of the Oxarart Member (subchron

32n.2n). It was found in the Castor section in the lower part of the Bearpaw Formation in subchrons 33n.2n to 33n.1r.

It was reported by Harker from Pierre Formation of Manitoba and the Pierre Shale of Wyoming, and by Zaitzeff and Cross (1970) from the (?) lower Maastrichtian of Texas. It has a published chronostratigraphic range from the Turonian to the Maastrichtian (Harker et al., 1990, p. 31).

Figured: GMUS 4335 B 016.2/110

Dinogymnium longicorne (Vozzhennikova) Harland 1973
emend. Lentin and Vozzhennikova 1990

Plate 1, Figure 3

1967 *Gymnodinium longicornis* Vozzhennikova, p.46, pl.1, fig.8; pl.3, fig.6; pl. 4, figs.6a-b,7)

1973 *Dinogymnium longicornis* (Vozzhennikova) Harland, p. 678, pl. 85, figs. 2-4.

1973 *Dinogymnium curvatum* Vozzhennikova, p. 43, pl. 1, fig. 10-12; pl. 4, fig. 2-3.

1975 *Dinogymnium longicornis* (Vozzhennikova) Harland *in* Wall and Singh, p. 1166, pl. 3, fig. 3.

1990 *Dinogymnium longicornis* (Vozzhennikova) Harland emend. Lentin and Vozzhennikova, p. 18-19, pl. 2, fig. 1-5.

1994 *Dinogymnium longicorne* (Vozzhennikova, Harland emend. Lentin and Vozzhennikova) Kurita and McIntyre, pl. 4.2, figs. 3, 4.

Remarks: The species is readily identified by its elongate spindle-shaped ambitus, with the epitheca being much longer than the hypotheca. An apical operculum was also observed in some specimens. In their emended description of the species, Lentin and Vozzhennikova (1990) stated that the specimen illustrated by Harland as *D. longicornis* was in actuality *Alisogymnium laeve* on the basis of the former emended species' much larger size. However, the specimens reported here possess the long, even curving, epitheca characteristic of *D. longicornis*, which appears to be much longer in relative proportion than in the specimen illustrated by Harland.

Dimensions: Cyst: length: 64 (86) 110 µm; width: 24 (37) 48 µm

Measured: 6

Occurrences: In addition to the specimens reported by Harland (1973), the species was also reported from the Bearpaw Formation and adjoining formations in the Western Interior by Wall and Singh (1975), Harker (1977), Harker et al. (1990), and Kurita and McIntyre (1994). It has a known stratigraphic range from the Senonian of Siberia and the Campanian to Maastrichtian of North America.

Figured: GSC 401350 015.5/80

Dinogymnium sibiricum (Vozzhennikova) Lentin and Williams

emend. Lentin and Vozzhennikova 1990

Plate 1, Figure 4

1967 *Dinogymnium sibiricum* Vozzhennikova, p.47-48, pl.2, figs.2, 3a-b; pl.3, figs. 2-3.

1973 *Dinogymnium sibiricum* (Vozzhennikova) Lentin and Williams, p. 50.

1990 *Dinogymnium sibiricum* (Vozzhennikova) emend. Lentin and Vozzhennikova, p. 21-22.

Remarks: Recovered specimens are smaller than the size range stated in the description of Lentin and Vozzhennikova (1990) (66-68 µm long, 37-38 µm wide, p. 22). The recovered specimens do possess the tapering epicyst and the shorter, conical "helmet-shaped" endocyst characteristic of the species. The differences in size are considered to be an acceptable infraspecific variation.

Dimensions: Cyst: length: 27 (38) 48 µm; width: 21 (33) 45 µm

Measured: 5

Occurrences: Specimens were recovered from the base (chron 33n) and upper half of the Manyberries Member (chron 32r to 32n.4r) in the Cypress Hills section. In the Castor section, specimens were recovered from the Dinosaur Park Formation at the base of the Castor core in subchron 33n.3r and from the Bearpaw Formation in subchron 33n.2n. The species was also reported from the Bearpaw Formation in the Alberta

Foothills by Kurita and McIntyre (1994) and from the Northwest Territories by McIntyre (1974). The species ranges from the Senonian to late Campanian in Siberia and western Canada.

Figured: GSC 401350 015.2/94

Subclass PERIDINIPHYCIDAE Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Order GONYAULACALES Taylor 1980

Suborder CERATIINEAE

Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Family CERATIACEAE Willey and Hickson 1909

Genus *Odontochitina* (Deflandre) Davey 1970

Odontochitina operculata (O. Wetzel) Deflandre and Cookson 1955

Plate 1, Figure 5; Plate 2, Figures 1, 2

1933 *Ceratium (Euceratium) operculatum* O. Wetzel, p. 170, pl. 2, figs. 21-22, text-fig. 3.

1935 *Odontochitina silicorum* Deflandre, p. 234, pl. 9, figs. 8-10.

1955 *Odontochitina operculata* (O. Wetzel) Deflandre and Cookson, p. 291-292, pl. 3, figs. 5-6

Remarks: Cysts of this species are highly distinctive, both with regards to its large size and unique shape. It differs from other species of *Odontochitina* in

lacking perforations, striations or other ornamentation on the periphragm and horns. Recovered material consists of isolated apical horns with an opercular cap or cysts with antapical horns, in varying states of preservation. One specimen was also found consisting of a hypocyst and antapical horns with a polygonal apical margin which may indicate precingular tabulation.

Dimensions: Cyst (hypocyst and antapical horns): length: 160 (185) 209 µm; width: 44 (61) 85 µm

Processes (isolated horns): 60 (70) 80 µm

Measured: 6

Occurrences: The last occurrence (LO) of the genus *Odontochitina* was considered by Antonescu et al. (2001) as being one of the biosignals marking the C-M boundary at the Tercis les Bains GSSP. This observation is also supported by the reports of McIntyre (1974, 1975) and Ioannides (1986) who found the LO of odontochitinids to occur during the latest Campanian in the Northwest Territories.

Harland (1973, 1977), Harker (1977) and Kurita and McIntyre (1994) reported recovery of the species from the Bearpaw Formation. Zaitzeff and Cross (1970) reported incidences of *O. "striatoperforata"* from sediments they interpreted to be earliest Maastrichtian in age from Texas, but in light of the large number of reports limiting the genus to the Campanian, this report should be rescrutinized. Williams et al.

(1993) reported a top range of 72.0 Ma for the species, which they regarded to be "Early Maastrichtian" (Williams et al., 1993, p. 122), but in view of the advances in chronostratigraphy (i.e. Gradstein et al., 2004) now place their date within the Campanian.

The species was found to range through almost the entire extent of the Manyberries Member in the Cypress Hills, from its base in chron 33n to the top of subchron 32n.4r. At Castor, the species is present through most of the Bearpaw shale, from subchron 33n.2r to 32n.6n.

Figured: Pl. 1 Fig. 5: GMUS 4216-1 021.5/105

Pl 2, Fig. 1, 2: GMUS 4262 A 018/116, GMUS 4242-1 015.5/114.2

Suborder GONIODOMINEAE

Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Family GONIODOMACEAE Lindemannn 1928

Subfamily PYRODINIODEAE

Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Genus *Hystrichosphaeridium* (Deflandre) Davey and Williams 1966b

Hystrichosphaeridium tubiferum (Ehrenberg) Deflandre 1937b

emend. Davey and Williams 1966b

Plate 1, Figure 6

1838 *Xanthidium tubiferum* Ehrenberg, pl.1, fig.16

1904 *Ovum hispidium (Xanthidium tubiferum)* Ehrenberg *in* Lohmann, p. 21.

1933b *Hystrichosphaera tubifera* (Ehrenberg) O. Wetzel, p. 40.

1937b *Hystrichosphaeridium tubiferum* (Ehrenberg) Deflandre, p. 68.

1966b *Hystrichosphaeridium tubiferum* (Ehrenberg) Deflandre emend. Davey and Williams, p. 56-58, pl. 6, figs. 1, 2; pl. 8, fig. 5; pl. 10, fig. 2; text-fig. 13.

Remarks: The observed specimens all possessed the spherical cyst and long tubular processes with the buccinate distal ends characteristic of the species as emended by Davey and Williams (1966b). The presence of paracingular processes and an apical archeopyle differentiate the genus from other chorate taxa possessing tubiform processes.

Dimensions: Cyst (excluding processes): diameter: 37 (43) 48 μm

Processes: 13 to 20 μm

Measured: 7

Occurrences: The species was reported by Ioannides (1986) from the arctic and from the Bearpaw Formation by Harker (1977), Harker et al. (1990) and Kurita and McIntyre (1994). Williams et al. (1993) reported a range of 111.0 to 49.0 Ma in the northern hemisphere for the species. It is found to range in the Cypress Hills through the upper three quarters of the Manyberries Member (upper half of chron 33n) in the Campanian to the lower Thelma Member (chron 31r) in the lowest Maastrichtian. Specimens were recovered from upper half of the Bearpaw Formation in the Castor core (subchron 33n.1n to the upper part of 32n.6n).

Figured: GMUS 4228-1 008/101.7

Hystrichosphaeridium tubiferum* var. *brevispinum Davey and Williams 1966b

Plate 1, Figure 7

1966b *Hystrichosphaeridium tubiferum* var. *brevispinum* Davey and Williams, p. 58, pl. 10, fig. 10.

Remarks: Specimens of this variety are recognizable by their shorter tubiform processes than seen in *H. tubiferum* var. *tubiferum*, which in the measured specimens were approximately half the length of the processes of specimens assigned to *H. tubiferum sensu stricto.* Harker et al. (1990) reported observing a range of process lengths between the two varieties, suggesting that difference in process length was likely due to morphologic variation in the motile stage.

Dimensions: Cyst (excluding processes): diameter: 40 (43) 56 µm

Processes: 6 to 9 µm

Measured: 7

Occurrences: This species has been reported by Ioannides (1986) from the arctic and Harland (1973) and Kurita and McIntyre (1994) from the Bearpaw Formation. The variety was found to range throughout the Cypress Hills section, from middle third of the Manyberries Member (chron 33n) to lower part of the Thelma Member (chron 31r). Isolated incidences were found in the Castor section: in two samples in the bottom third of the Bearpaw Formation in subchron 33n.2n, one sample in the lower half of chron 32r, and in the uppermost sample prior to the transition into the Horseshoe Canyon Formation in subchron 32n.5r.

Figured: GMUS 4278-1 020.3/87

Hystrichosphaeridium arborispinum Davey and Williams 1966b

Plate 1, Figure 8

1966b *Hystrichosphaeridium arborispinum* Davey and Williams, p. 61, pl. 9, figs 5, 10.

Remarks: Cysts are more ovoidal in shape than *H. tubiferum*. They have processes that are more slender and fibrous, flaring distally into recurved, serrate frills. The cyst body is smooth to microgranulate in texture, more similar to *H. cf. arborispinum* recovered by Harland (1973) and Kurita and McIntyre (1994) than the specimens reported by Harker as having a "lightly granular to reticulate periphragm" (Harker et al., 1990, p. 58).

Dimensions: Cyst: length: 32 (41) 56 µm; width: 29 (39) 56 µm

Processes: 8 to 17 µm

Measured: 9

Occurrences: In the Cypress Hills, *H. arborispinum* first occurs in the Manyberries Member at the same level as *H. tubiferum* and *H. tubiferum* var. *brevispinum* (upper half of chron 33n). However, its last occurrence is somewhat earlier, in the Belanger Member prior to the C-M boundary (subchron 32n.1n). Only one occurrence was found in the Castor section (sample 356) in the lower half of subchron 33n.2n.

A form identified by Harland (1973) as *H.* cf. *arborispinum* from the Bearpaw Formation was rejected by Harker et al. (1990). A similar form

was also compared to the species by Kurita and McIntyre (1994) from the Bearpaw Formation near Calgary, but they did not state if their comparison was different from Harland's interpretation. They also identified *bona fide* individuals of this species in their study. It was first recognized from the Barremian of England and has been observed from sediments ranging through the Senonian.

Figured: GMUS 4278-1 007.5/105

Suborder GONYAULACINEAE Lindemann 1928

Family GONYAULACACEAE Lindemann 1928

Subfamily CRIBOPERIDINIOIDEAE

Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Genus *Criboperidinium* Neale and Sarjeant 1962 emend. Helenes 1984

Criboperidinium exilicristatum (Davey) Stover and Evitt 1978

Plate 3, Figure 1

1969 *Gonyaulacysta exilicristata* Davey, p.121, pl.1, figs.1-2; text-figs.9A-B.

1978 *Criboperidinium exilicristatum* (Davey) Stover and Evitt, p. 150.

Remarks: The recovered specimens are similar in appearance to the type material, possessing a prominent apical horn and poorly defined sutural crests that make it difficult to discern paratabulation. The lower end of the size range of the recovered specimens is smaller than that published by Davey (1969) with the type material, but this is considered to be within an

acceptable degree of intraspecific variation. The form *Criboperidinium* sp. A (Ioannides, 1986) may, based on inspection of illustrations, also belong to this species.

Dimensions: Cyst: length: 40 (65) 96 µm; width: 30 (50) 79 µm

Apical Horn: 8 to 30 µm long

Measured: 18

Occurrences: Specimens were recovered from the Cypress Hills section from the Manyberries Member (chron 33n through subchron 32n.4n), with one possible specimen recovered from the Thelma Member in chron 31r. Specimens were recovered from the lower half of the Castor core from subchrons 33n.2n through 33n.1n.

The species was also reported by Kurita and McIntyre (1994) from the Oldman and Bearpaw formations from sections in the southern Alberta plains and from the Bearpaw in the Alberta foothills. Ioannides (1986) reported recovery of his *Criboperidinium* sp. A from Campanian strata on Devon Island in the Canadian Arctic. It has also been reported from Cenomanian strata from Alberta (Singh, 1983) and Saskatchewan (Davey, 1969). Stratigraphic range: Cenomanian (Davey, 1969; Fensome and Williams, 2004) through Campanian into the early Maastrichtian (Kurita and McIntyre, 1994; this study).

Figured: GSC 401338 004.5/96

Genus *Florentinia* (Davey and Verdier) Duxbury 1980

Florentinia mantellii (Davey and Williams) Davey and Verdier 1973

Plate 3, Figure 2

1966b *Hystrichosphaeridium mantellii* Davey and Williams, p. 66, pl. 6, fig. 6.

1973 *Florentinia mantellii* (Davey and Williams) Davey and Verdier, p. 187-188, 191, pl. 1, figs. 1, 4, 7; pl. 4, figs. 1, 3.

Remarks : The recovered specimens all resemble the type material, with subspherical cyst body, large hollow antapical process, and smaller, narrower paracingular processes. An irregular 'torn' precingular archeopyle is present.

Dimensions : Cyst: length: 40 (48) 56 µm; width: 39 (44) 53 µm

Processes: precingular: 8 to 13 µm; antapical: 13 to 16 µm

Measured: 5

Occurrences : The species is confined to the Manyberries Member in the Cypress Hills section, chron 33n to subchron 32n.4r. It was not recovered from the Castor section. Ioannides (1986) reported the species from the Campanian strata on Devon Island in the Canadian Arctic. Known stratigraphic range: late Cenomanian to late Campanian.

Figured : GMUS 4262 A 024/101

Genus *Spongodinium* (Deflandre) Stover and Evitt 1978

Spongodinium delitiense (Ehrenberg) Deflandre emend. Lucas-Clark 1987

Plate 3, Figure 3

1838 *Peridinium delitiense* Ehrenberg, p. 110, pl. 1, figs. 1-6.

1936 *Spongodinium delitiense* (Ehrenberg) Deflandre, p. 170-171.

1986 *Spongodinium? delitiense* (Ehrenberg) Deflandre *in* Ioannides, p. 37, pl. 7, figs. 4-11; pl. figs. 2-5.

1987 *Spongodinium delitiense* (Ehrenberg) Deflandre emend. Lucas-Clark, p. 167, pl. 3, figs. 1-16; text-fig. 4.

Remarks: Recovered specimens are often fragmentary, ranging from isolated paraplates *sensu* Harker et al. (1990) and illustrated by Ioannides (1986) to large subspherical cysts with or without an intact apical horn. The variation in size and shape lead Lucas-Clark (1987) to suggest in her emended description that *S. delitiense* probably represents more than one distinct species. The possibility also exists that the variation may be due to taphonomic changes to the vesicular structure of the cyst wall.

Dimensions: Cyst: length: 44 (82) 121 μm; width: 32 (76) 120 μm
Measured: 14 (whole specimens only)

Occurrences: The species is restricted to the Manyberries Member in the Cypress Hills section (chron 33n to subchron 32n.3r). It was found to occur in three distinct zones within the Castor core: in the Dinosaur Park Formation (subchron 33n.1n), in the middle Bearpaw Shale unit (subchron 33n.1n) and in the Bearpaw transition zone (subchron

32n.5r). *S. delitiense* was also reported from the Santonian to Palaeocene of the Canadian Arctic (McIntyre, 1974; Ioannides, 1986) and from the Bearpaw and adjacent formations by Harker (1977), and Harker et al. (1990). Williams et al. (1993) report a stratigraphic range of 79.0 to 64.0 Ma for the species.

Figured: GMUS 4224 B 021/104.5

Subfamily GONYAULACOIDEAE Lindemann 1928

Genus *Achomosphaera* Evitt 1963

Achomosphaera ramulifera (Deflandre) Evitt 1963

Plate 3, Figure 4

1937 *Hystrichosphaeridium ramuliferum* Deflandre, p.74, pl. 3, figs. 7-9, pl.14, figs. 5-6.

1963 *Achomosphaera ramulifera* (Deflandre) Evitt, p. 163.

Remarks: The recovered specimens all have the spiny, bifurcate and trifurcate processes characteristic of the genus. Several of the observed specimens possess weakly-developed septa connecting the bases of some or all of the processes, a feature that has been reported by several workers, including Davey and Williams (1966a), Stover and Evitt (1978) and Harker et al. (1990). Isolated plates, possibly representing the operculum of the precingular archeopyle were also observed, with at least one specimen having a granulate texture.

Dimensions: Cyst: length: 40 (57) 81 µm; width: 32 (49) 64 µm

Processes: 13 to 29 µm

Measured: 6

Occurrences: The species was reported from the Northwest Territories by McIntyre (1974) and Ioannides (1986) and from the Bearpaw Formation by Harker et al. (1990) and Kurita and McIntyre (1994). In the studied sections, whole and fragmented specimens were found to range from the lower part of the Manyberries Member (chron 33n) to the middle of the Belanger Member (subchron 32n.1n) in the Cypress Hills. One specimen was recorded from the middle Bearpaw shale unit from Castor (33n.1n). It has a reported range from the Valanginian to the Recent (Harker et al., 1990, p. 49).

Figured: GMUS 4278-1 013/105

Genus *Pterodinium* (Eisenack) Yun 1981

Pterodinium cingulatum (O. Wetzel) Below 1981

Plate 4, Figure 1

1933 *Cymatiosphaera cingulata* O. Wetzel, p.28, pl. 4, fig. l0.

1954 *Hystrichosphaera cingulata* (O. Wetzel) Deflandre, p. 258.

1967 *Hystrichosphaera cingulata* (O. Wetzel) Deflandre var. *cingulata* Clarke and Verdier, p.45, pl. 8, figs. 9, 10.

1970a *Spiniferites cingulatus* (O. Wetzel) Sarjeant, p. 76.

1971 *Spiniferites cingulatus* var. *cingulatus* (O. Wetzel) Davey and Verdier, p. 32.

1981 *Pterodinium cingulatum cingulatum* (O. Wetzel) Below, p.114.

Remarks: The observed specimens conform to the type material, with their distinctive 'wing-like' parasutural crests and precingular archeopyle.

Dimensions: Cyst: length: 32 (41) 48 µm; width: 24 (39) 48 µm

Crests: 5 to 8 µm

Measured: 4

Occurrences: Specimens were recovered from the upper half of the Manyberries Member (chron 32r to subchron 32n.4n) and the top of the Thelma Member (chron 31r) in the Cypress Hills section. The species was found to range into the middle of the Bearpaw Formation in the Castor section from subchrons 33n.1r through 33n.1n.

The species was reported by Ioannides (1986) from the Canadian Arctic and by Harker et al. (1990) from the Lea Park Formation of Saskatchewan and the Pierre Formation in Manitoba. It was reported from the Campanian of Texas by Harker (1977) and Heine (1991). Kurita and McIntyre (1994) reported a *'Pterodinium* sp.*'* from the Bearpaw, along with *Pterodinium agadirense.* Nøhr-Hansen (1996) also reported *'Pterodinium* spp.*'* from Western Greenland without illustration. Harker et al. (1990, p. 52) report the species' range as Albian to Pleistocene, with some reservation expressed regarding reports from post-Cretaceous strata.

Figured: GMUS 4244-1 021/101.5

Genus *Spiniferites* (Mantell) Sarjeant 1970a

Spiniferites ramosus (Ehrenberg) Mantell 1854

Plate 4, Figures 2, 3, 4

1838 *Xanthidium ramosus* Ehrenberg, pl. 1 figs. 1-2, 5.

1854 *Spiniferites ramosus* (Ehrenberg) Mantell, p. 239.

1904 *Ovum hispidum* subsp. *ramosum* Lohmann, p. 25 nom. nud.

1935 *Hystrichosphaera furcata* Deflandre, p. 214, pl. 5, fig. 9l pl. 8, fig. 3.

1937 *Hystrichosphaera ramosa* (Ehrenberg) Deflandre, p. 64, pl. 11, figs. 5, 7.

1938 *Bion ramosum* (Ehrenberg) Eisenack, p. 243, pl. 16, fig. 5.

1969 *Spiniferites ramosus* (Ehrenberg) Mantell *in* Wall and Dale, p. 48, text-figs. 1-9, pl. 1, figs. 1-15.

Remarks: Recovered specimens demonstrate the morphological diversity that has been remarked upon by other workers. Processes are solid and vary in length and thickness, possessing both bifurcate and trifurcate tips. Overall shape was subspherical to ovoidal, with precingular archeopyles apparent in some cases. Observed specimens were not classified or counted to the variety/subspecies level, although some individuals could have been placed into the *ramosus* or *gracilis* varieties.

Dimensions: Cyst: length: 24 (45) 53 µm; width: 24 (33) 40 µm

Processes: 7 to 16 µm

Measured: 8

Occurrences: This very long-ranging species has been reported by workers throughout the Western Interior, from the Turonian to Maastrichtian. In addition to definite specimens of *S. ramosus*, Harland (1973) also reported instances of the varieties *granosus* and *gracilis*.

The species was found to range throughout the Cypress Hills section, from the bottom of the Manyberries Member in chron 33n to the uppermost part of the Thelma Member in chron 31r, although a hiatus was noted through most of the Belanger Member and the lower two thirds of the Thelma Member. In the Castor section, the species was found to range throughout, although it was confined to three distinct zones: a lower zone, spanning subchrons 33n.2n and 33n.1r; a middle zone encompassed by subchron 33n.1n; and an upper zone in the uppermost part of the Bearpaw in subchron 32n.5r.

Globally, the species has been found to range from the Valanginian (Early Cretaceous) to the Recent (Harker et al., 1990, p. 43).

Figured: GMUS 4292 A 003/115, GMUS 4272 A 016.5/112, GMUS 4193 008/112

Spiniferites membranaceous (Rossignol) Sarjeant 1970

Plate 4, Figure 5

1964 *Hystrichosphaera furcata* var. *membranacea* Rossignol, p. 86, pl.1, figs. 4, 9-10.

1970a *Spiniferites membranaceous* (Rossignol) Sarjeant, p. 76.

1973 *Spiniferites cf. membranaceous* (Rossignol) Sarjeant *in* Harland, p. 692, pl. 87, fig. 11.

Remarks: The recovered specimens show a degree of variation in the membranaceous septa that give the species its name, particularly in regards to the antapical processes. The specimens conform well to those reported by Davey and Williams (1966a) and to *Spiniferites* cf. *membranaceous* reported by Harland (1973), who made the distinction due to the reduction or absence of the antapical crests illustrated on the holotype by Rossignol (1964, fig. 4). However, Rossignol did figure a specimen in the same paper (*ibid.*, fig. 10) with crests that are considerably reduced in size from those of the holotype that conforms fairly well to the specimen illustrated by Harland and also recovered in this study. This difference is thus considered to be within a range of variation typical of this species.

Dimensions: Cyst: length: 32 (40) 45 µm; width: 24 (33) 39 µm

Processes: 5 to 21 µm

Measured: 8

Occurrences: In the Cypress Hills, the species was found to occur in the middle of the Manyberries Member (chrons 32r and 32n.6n) and the Oxarart Member (chron 32n.2n). It was not recovered from the Castor section. The species is known to have a range from the Campanian to the Recent. Dale (1976) and Dodge (1989) both reported recovering this cyst from cultures of the extant motile form *Gonyaulax spinifera.*

Figured: GMUS 4268-1 019.5/104.8

Spiniferites pseudofurcatus (Klumpp) Sarjeant emend. Sarjeant 1981

Plate 4, Figure 7

1953 *Hystrichokibotium pseudofurcatus* Klumpp, p.388, pl.16, figs.12, 14.

1970a *Spiniferites pseudofurcatus* (Klumpp) Sarjeant, p. 76.

1981 *Spiniferites pseudofurcatus* (Klumpp) Sarjeant emend. Sarjeant, p.108-109, pl. 3, figs. 1-2.

Remarks: This species is distinct in possessing three trifurcated antapical processes that are larger than the other processes, all of which terminate distally with bifurcated tips.

Dimensions: Cyst: length: 39 (46) 58 µm; width: 32 (43) 48 µm
Processes: 9 to 16 µm
Measured: 5

Occurrences: The species is present in the Cypress Hills section, from the middle third of the Manyberries Member to the lower third of the Thelma Member (chron 33n to 31r). It was confined to the upper half of the Bearpaw stratum in the Castor core (33n.1n to 32n.5r). It was also reported from the Bearpaw Formation by Kurita and McIntyre (1994) and from the Pierre and Lea Park formations of Manitoba and Saskatchewan by Harker (1977). The species has a published range

from the Turonian to the Eocene and possibly Pliocene, although Harker et al. (1990) suggested that any recovery from strata younger than Eocene in age warrant closer examination for evidence of reworking.

Figured: GMUS 4216-1 012.5/107.5

Subfamily UNCERTAIN

Genus *Fibrocysta* Stover and Evitt 1978

Fibrocysta vectensis (Eaton) Stover and Evitt 1978

Plate 4, Figure 6

1976 *Lanternosphaeridium vectensis* Eaton, p.275-276, pl.12, figs.4-6

1978 *Fibrocysta vectensis* (Eaton) Stover and Evitt, p. 155.

Remarks: The recovered specimens resemble those figured by Ioannides (1986) who used open nomenclature because the apical processes and larger "protrusion are not always distinctly differentiated." (*ibid.,* p. 23). This was not found to be the case in the recovered material, although in one case the apical protrusion appears to actually be somewhat fibrous. Both acuminate processes with closed distal tips and hollow processes with bifid tips were identified. A precingular, operculum-free archeopyle was present.

Dimensions: Cyst: length: 54 (68) 85 µm; width: 32 (40) 48 µm

Processes: 5 to 31 µm (the larger processes being apical and antapical)

Measured: 5

Occurrences: Recovered specimens were limited to the middle third of the Manyberries

Member in the Cypress Hills section (chrons 33n to 32r). It was also reported by Ioannides (1986) from the Northwest Territories, Canada. It has a reported stratigraphic range from the late Santonian (Ioannides, 1986) to the Eocene (Fensome and Williams, 2004).

Figured: GMUS 4321 A 106.5/117

Family AREOLIGERACEAE Evitt 1963b

Genus *Circulodinium* Alberti 1961

***Circulodinium disinctum* (**Deflandre and Cookson) Jansonius 1986

Plate 5, Figures 1, 2

1955 *Cyclonephelium distinctum* Deflandre and Cookson, p. 285-286, pl. 2, fig. 14, text-figs. 47-48.

1961 *Circulodinium deflandrei* Alberti, p. 29, pl. 4, figs. 7-13.

1973 *Cyclonephelium distinctum* (Deflandre and Cookson) *in* Harland, p. 689, pl. 87, figs. 1, 4.

1986 *Circulodinium distinctum* (Alberti) Jansonius, p. 204.

Remarks: The recovered specimens conform to the type material. The numerous short processes were either acuminate or bifid and occasionally joined to form loops or lamellae. Recovered material included intact specimens as well as individuals that were either compressed or missing the epicyst entirely.

Dimensions: Cyst: length: 56 (86) 120 µm; width: 56 (76) 105 µm

Processes: 2 to 15 µm

Measured: 8

Occurrences: In the Cypress Hills section, the species was found to occur from the bases of the RCA Thelma core in the Manyberries Member (chron 33n) through the base of the Belanger Member (subchron 32n.1r). It occurs in two distinct locations within the Castor core, from 33n.1r through 33n.1n in the Bearpaw Formation, and from the Horseshoe Canyon Formation in subchron 32n.5n.

The species was reported as *Cyclonephelium distinctum* by Harland (1973, 1977) from the Bearpaw Fomation in Alberta and Montana, by Ioannides (1986) from the Canadian Arctic, and by Harker (1977) and Harker et al. (1990) from the Lea Park, Judith River and Pierre formations of Saskatchewan and Manitoba, and was considered to be an important constituent of Harker's parazone M7. Williams et al. (1993) published a stratigraphic age range from 132.0 to 66.0 Ma (Hauterivian to Maastrichtian).

Figured: GMUS 4242-1 006/121, GSC 401338 018/104.2

Suborder UNCERTAIN

Family UNCERTAIN

Subfamily UNCERTAIN

Genus *Downiesphaeridium* Islam 1993

Downiesphaeridium armatum (Deflandre) Islam 1993

Plate 5, Figure 3

1937 *Hystrichosphaeridium armatum* Deflandre, p.76-77, pl.16, fig. 6.

1964 *Baltisphaeridium armatum* (Deflandre) Downie and Sarjeant, p. 91.

1969 *Cleistosphaeridium armatum* (Deflandre) emend. Davey, p.153, pl. 8, figs. 1, 2, 12.

1993 *Downiesphaeridium armatum* (Deflandre) Islam, p. 84.

Remarks: The specimens resemble the holotype of Deflandre (1937) in appearance, although the maximum size is larger.

Dimensions: Cyst: length: 26 (40) 48 μm; width: 24 (40) 48 μm

Processes: 6 (10) 14 μm

Measured: 5

Occurrences: In the Cypress Hills section, the species ranges through the upper three-quarters of Manyberries Member (chrons 33n to 32n.3r) and is absent from the Oxarat and Belanger members, with one occurrence at the top of the Thelma Member (chron 31r). It was absent from the Castor section.

The species was reported as *Cleistosphaerdium armatum* from Alberta by Kurita and McIntyre (1994). It was also reported from Cenomanian

strata of Alberta by Singh (1983). Its maximum reported range of Albian to Maastrichtian occurs in Europe (Harker et al., 1990, p. 69).

Figured: GMUS 4352-1 018.5/111.2

Downiesphaeridium? aciculare (Sarjeant ex Davey) Islam 1993

Plate 5, Figure 4

1967a *Cleistosphaeridium aciculare* Sarjeant, p. 331 nom. nud.

1969 *Cleistosphaeridium? aciculare* Sarjeant ex Davey, p.158, pl.6, figs.11-12.

1974 *Cleistosphaeridium* sp. cf. *C. aciculare* Sarjeant ex Davey *in* McIntyre, pl. 12, figs. 10, 11.

1993 *Downiesphaeridium aciculare* (Sarjeant ex Davey) Islam, p. 83-84.

2004 *Downiesphaeridium? aciculare* (Davey) *in* Fauconnier and Masure, p. 196.

Remarks: The chorate cysts are spherical to subspherical in shape, with solid, 'needle-like' acuminate processes that are of uniform breadth (i.e. uniformly fine and dense or broader and more sparse). Davey (1969) tentatively assigned the species to the genus as he could not discern an apical archeopyle. None could be clearly discerned in the material studied from the Bearpaw Formation.

Dimensions: Cyst: length: 32 µm; width: 32 (40) 48 µm

Processes: 8 to 12 µm

Measured: 4

Occurrences: The species was found to be confined to the lower Manyberries Member in the Cypress Hills (chron 33n). The recovered specimens are similar to

those recovered by McIntyre (1974) and Ioannides (1986) from the Northwest Territories and from the Cenomanian to Turonian of Alberta by Singh (1983) and Sweet and McIntyre (1988). Harker et al. (1990) reported the species from the Lea Park Formation near Saskatoon. It has a known range from the Barremian to the Campanian.

Figured: GMUS 4248-1 010.5/115.8

Downiesphaeridium sp. A

Plate 5, Figures 5, 6

1966 *Cleistosphaeridium diversispinosum* Davey, Downie, Sarjeant and Williams, p. 167, pl. 10, fig. 7.

1973 *Cleistosphaeridium diversispinosum* (Davey, Downie, Sarjeant and Williams) Harland, p. 684, pl. 86, fig. 1.

1990 *Cleistosphaeridium diversispinosum* (Davey, Downie, Sarjeant and Williams) Harker and Sarjeant *in* Harker, Sarjeant and Caldwell p. 68, pl. 2, figs. 14, 15.

1994 *Cleistosphaeridium diversispinosum* (Davey, Downie, Sarjeant and Williams) Kurita and McIntyre, 80, pl. 4.2, fig. 16.

Description: Late Cretaceous skolochorate gonyaulacoid cyst with solid tubular processes which are usually slender and distally acuminate or branched. Process length varies. Autophragm finely granular. Archeopyle apical with zig zag suture, operculum free.

Remarks: The observed specimens conform closely to the other reports from the Bearpaw Formation of *Cleistosphaeridium diversispinosum* (Harland,

1973; Harker et al., 1990; Kurita and McIntyre, 1994) and bear a strong resemblance to the original type material. All possess a 'zig-zag' apical archeopyle and solid processes that are extremely diverse in length, thickness and structure of their extremities.

However, in their emendation of the genus *Cleistosphaeridium* and the species *C. diversispinosum,* Eaton et al. (2001) disqualified the previous reports from the Bearpaw Formation as they neither conform to the specifics of the emended diagnosis nor the age range of Early Eocene to Oligocene. Specifically, the previous reports by Harker et al. (1990) and Harland (1973) were rejected as the illustrated figures lacked the "pick-like" or "dolabrate" processes of the emended description; the specimen illustrated by Kurita and McIntyre (1994) was rejected as it too lacked dolabrate processes and were considered to be too short.

Dimensions: Cyst: length: 24 (46) 56 µm; width: 27 (45) 56 µm

Processes: 8 to 15 µm

Measured: 6

Occurrences: Cypress Hills section: Manyberries Member from upper half of chron 33n to 32n.3r. Castor section: throughout the Bearpaw strata, concentrated in the lower part of the section (chrons 33n.2r and 33n.2n).

Figured: Holotype: GMUS 4242 A 019.8/105; GMUS 4228-1 012.5/110

Genus *Dapsilidinium* Bujak, Downie, Eaton and Williams 1980

Dapsilidinium marinum Singh 1983

Plate 6, Figure 1

1983 *Dapsilidinium marinum* Singh, p. 121, pl. 41, figs. 7-9.

1994 *Dapsilidinium* sp. B Kurita and McIntyre, pl. 4.2, fig. 10.

Remarks: The recovered specimens resemble the specimens described by Singh (1983) from the Cenomanian Upper Shaftesbury and Dunvegan formations of northern Alberta. The specimens consist of a spherical to subspherical autocyst possessing an apical archeopyle and distally open, hollow, intratabular processes. Some specimens also resemble the "sp. B" figured in Kurita and McIntyre (1994) from the Alberta foothills, although the authors did not provide any description or explanation as to their choice of open nomenclature. Singh (1983) also suggested that the specimens with apical archeopyles described as *Polysphaeridium subtile* by Harland (1973) from the Bearpaw Formation and McIntyre (1974) from the Northwest Territories were in fact *D. marinum*. Considering that Bujak et al. (1980) emended the genus *Polysphaeridium* as having an epitractal archeopyle, Singh's assertion is accepted here.

Dimensions: Cyst: Width 29 (44) 56 μm; Length 29 (39) 48 μm

Processes: 6 (15) 20 μm

Measured: 9

Distribution: Cypress Hills section through the upper two-thirds of the Manyberries

Member (chron 33n) to roughly the middle of the Oxarart Member (subchron 32n.2n). The species ranges throughout the lower half of the Castor section (subchrons 33n.2r to 33n.1n). Inferred stratigraphic range: Cenomanian to Earliest Maastrichtian.

Figured: GMUS 4258-1 012.5/110

Genus *Exochosphaeridium* Davey, Downie, Sarjeant and Williams 1966

Exochosphaeridium* cf. *phragmites Davey, Downie, Sarjeant and Williams 1966

Plate 6, Figure 2

1966 *Exochosphaeridium phragmites* Davey, Downie, Sarjeant and Williams p. 165-166, pl. 2, figs. 9, 10.

1973 *Exochosphaeridium* cf. *phragmites in* Harland, p. 687-688, pl. 86, fig. 10.

Description: Chorate, subspherical autocyst with precingular archeopyle. Processes numerous, mostly solid and fibrous, tapering and distally acuminate. A larger, foliate apical process is often hollow, branching and distally acuminate.

Remarks: The recovered specimens are similar to *Exochosphaeridium* cf. *phragmites* reported by Harland (1973) in that the processes are shorter in length than the holotype of Davey et al., 1966.

Dimensions: Autocyst: Length 24 (38) 52 μm; Width: 37 (45) 51 μm; Processes: 5 to 16 μm

Measured: 5

Distribution: Cypress Hills section: Manyberries Member from the upper half of chron 33n to the lower part of chron 32n.5n. *E. phragmites* was reported from the Bearpaw of Saskatchewan by Harker (1977). It has a reported stratigraphic range from the Albian to possibly the Maastrichtian (Harker et al., 1990, p. 73).

Figured: GMUS 4272-1 003.5/110

Genus *Microdinium* Cookson and Eisenack emend. Stover and Evitt 1978

Microdinium* cf. *ornatum Cookson and Eisenack 1960

Plate 6, Figure 3

1960 *Microdinium ornatum* Cookson and Eisenack, p. 6-7, pl. 2, figs. 3-8, text-figs. 2-4

1973 *Microdinium* cf. *irregulare* (Clarke and Verdier) Harland, p. 675-676, pl. 85, figs. 15, 16.

Description: Cyst proximate, spheroid in shape composed of endocyst and pericyst, the latter forming parasutural crests. Cyst wall smooth to microgranulate in texture. Parasutural crests smooth or possibly very finely perforate. Epitract smaller than hypotract; cingulum narrow, planar and demarcated by crests. Archeopyle apical, operculum free. Paratabulation 4', 6'', ?6c, 6''', ?1p, 1'''', ??s.

Remarks: Specimens resemble the holotype material, except for a larger size. They also closely resembles *Microdinium* cf. *irregulare* reported by

Harland (1973), with the exception of having a larger upper size range. Below (1987) considered *Microdinium irregulare* to actually belong to the genus *Micrhystridium*, leading to the conclusion that those specimens identified by Harland as "cf. *irregulare"* are more appropriately considered as cf. *ornatum* as they are here.

The crests on some of the specimens appear to be very finely perforated, a trait noted by Cookson and Eisenack (1960) on the holotype of *M. ornatum*, whereas Harland noted in his description that the crests were all smooth. It cannot be determined if this ornamentation is an actual trait or the result of damage. The size range reported here does fit well with the range reported by Harker et al. (1990). It is difficult to compare the recovered specimens with those of *M. ornatum* reported by Wall and Singh (1975), although the specimens recovered here have larger crests than those figured by them, suggesting the possibility that the difference is due to intraspecific variation.

Dimensions: Cyst: length: 24 (35) 48 μm; width: 24 (35) 48 μm

Crest height: 1 to 3 μm

Measured: 20

Occurrences: Harland (1973) reported recovery of his "*M.* cf. *irregulare"* from the Bearpaw Formation of Alberta, while poorly preserved specimens of *M. ornatum* were recovered by Harker (1977) from the Bearpaw Formation of Saskatchewan. Wall and Singh (1975) reported this species as part of their "Bearpaw flora" from the Buffalo Head Hills of Alberta. Singh

(1983) reported the species from the Cenomanian of Alberta. McIntyre (1974) and Ioannides (1986) reported recovery of *M. ornatum* and several other related forms from the Santonian to Maastrichtian of the Northwest Territories.

Specimens ranged in the Cypress Hills from the middle of chron 33n in the Manyberries Member to the middle of the Oxarart Member in subchron 32n.2n, with the possible recovery of two individuals from the top of the Thelma Member in chron 31r. In the Castor Core, the species was found to occur in the middle of the section, centered in subchron 33n.1n, with another occurrence of two individuals near the top of the Bearpaw stratum in subchron 32n.5r.

Williams et al. (1993) stated a geochronological range from 101 to 58 Ma for the species.

Figured: GMUS 4262-1 010.5/102

Genus *Prolixosphaeridium* (Davey, Downie, Sarjeant and Williams)

emend.Davey 1969a

Prolixosphaeridium parvispinum (Deflandre)

Davey, Downie, Sarjeant and Williams 1966

Plate 6, Figure 4

1937 *Hystrichosphaeridium xanthiopyxides* var. *parvispinum* Deflandre, p.77, pl.16 (al. pl. 13), fig. 5.

1958 *Hystrichosphaeridium parvispinum* (Deflandre) Cookson and Eisenack, p.45.

1960 *Baltisphaeridium parvispinum* (Deflandre) Klement, p.59.

1969 *Prolixosphaeridium parvispinum* (Deflandre) Davey, Downie, Sarjeant and Williams, p. 17.

Remarks: The recovered specimens closely resemble the type material, with an elongate proximochorate autocyst, truncated by the loss of an apical operculum. The autophragm is covered with coarse, simple spinelets. The genus differs from *Tanyosphaeridium* in having distally tapered, closed processes.

Dimensions: Cyst: length: 40 (51) 61 µm; width: 24 (28) 32 µm

Processes: 6 to 19 µm

Measured: 3

Occurrences: This species occurs solely in the Manyberries Member in the Cypress Hills section from chron 33n through 32r. The species has not been reported previously within the Western Interior Basin, although Ioannides (1986) reported recovery of specimens of *P. granulosum* and an unnamed species from the Campanian of the Northwest Territories. The species was reported by Schiøler et al. (1997) from the ENCI Quarry near Limburgh, the type section for the Maastrichtian. Inferred

age range: Aptian to Maastrichtian, based on reports listed here and the age of the type material.

Figured: GMUS 4272 A 009/110

Genus *Tanyosphaeridium* Davey and Williams 1966

Tanyosphaeridium variecalamum Davey and Williams 1966b

Plate 6, Figure 5

1966b *Tanyosphaeridium variecalamum* Davey and Williams, p. 98-99 p1.6, fig.7; text-fig.20.

Remarks: The recovered specimens closely resemble the type material, with the distinctive elongate autocyst with granular surface ornamentation and hollow processes with slightly expanded distal tips. All possess an apical archeopyle with free operculum.

Dimensions: Cyst: length: 24 (36) 48 µm; width: 17 (23) 32 µm

Processes: 8 to 14 µm

Measured: 7

Occurrences: This species occurs intermittently throughout the Manyberries Member in the Cypress Hills section, from the upper part of chron 33n to the top of subchron 32n.4n. Specimens were also found sporadically throughout the Castor core, ranging from subchron 33n.2r through 32n.5r. It was previously reported from the Bearpaw Formation by Harland (1973), Harker (1977) and Kurita and McIntyre (1994). It was also reported from the Northwest Territories by Ioannides (1986). Its published

distribution is the Aptian to Maastrichtian (Harker et al., 1990).

Figured: GMUS 4214A 013.5/103

Subfamily LEPTODINIOIDEAE

Fensome, Taylor, Norris, Sarjeant, Wharton and Williams 1993

Genus *Gonyaulacysta* Deflandre 1964 emend. Sarjeant 1982

Plate 6, Figure 6

Gonyaulacysta* cf. *eisenackii (Deflandre) Dodekova 1965 emend. Sarjeant 1982

1939 *Gonyaulax eisenackii* Deflandre, p. 171, pl.6, figs.7-8; text-figs.3-4.

1967 *Tubotuberella sphaerocephalus* (Deflandre)Vozzhennikova, p. 181, pl. 103, figs. 2, 3a-b.

1967 *Gonyaulacysta eisenackii* (Deflandre) Dodekova, p. 18-19, pl. 2, figs. 9-11.

1970 *Endoscrinum eisenackii* (Deflandre) Gocht, p. 146-147, pl. 33, figs. 9-12, text-fig. 15f.

1978 *Tubotuberella eisenackii* (Deflandre) Stover and Evitt, p. 197.

1982 *Gonyaulacysta eisenackii* (Deflandre) Dodekova emend. Sarjeant, p.32-33, pl. 7, figs. 5-6; pl. 8, fig. 3; text-fig 4.

Remarks: The recovered specimens resemble the material figured by Sarjeant (1982), with an elongate asymmetrically pentagonal ambitus. The paraplate boundaries are marked by irregularly denticulate to echinate crests and the apex terminates in the mamelon typical of the genus. The crests are far more ornate than *Criboperidinium* and the asymmetric

tabulation does not place the specimens within *Alterbidinium* or *Spinidinium.* The recovered specimens are compared to the species due to the large extension in the species' range, from the Middle Jurassic to the Late Cretaceous.

Dimensions: Cyst: length: 43 (68) 113 µm; width: 31 (48) 64 µm

Measured: 23

Occurrences: This is the first report of this species from the Late Cretaceous of Western Canada. It was reported by Fensome (1979) from the Upper Jurassic-Lower Cretaceous of Greenland. Williams et al. (1993) give an age range of 166.0 to 144.0 Ma for this species. The recovered specimens range throughout the Cypress Hills section (chrons 33n to 31r) with a hiatus from the upper part of the Manyberries Member to the middle of the Oxarart Member (subchrons 32n.4n to 32n.2n).

Figured: GMUS 4258-1 013.5/106

Genus *Oligosphaeridium* Davey and Williams 1966

Oligosphaeridium complex (White) Davey and Williams 1966b

Plate 6, Figure 7

1842 *Xanthidium tubiferum* var. *complex* White, p. 39, pl. 4, fig. 11.

1848 *Xanthidium complexum* (White) Bronn, p. 1375.

1940 *Hystrichosphaeridium elegantulum*, Lejeune-Carpentier, p. 22, test-figs. 11, 12.

1952 *Hystrichosphaeridium complex* (White) Firtion, p. 156, pl. 9, figs., 2, 4, 5; text-figs. 1A-F.

1955 *Hystrichosphaeridium complex* (White) Valensi, p. 592, pl. 4. fig. 3.

1962 *Hystrichosphaeridium tubiferum* (Ehrenberg) Pocock, p. 83, pl. 15, fig. 230.

1966b *Oligosphaeridium complex* (White) Davey and Williams *in* Davey, Downie, Sarjeant and Williams, p. 71, p1.7, fig. 1.

Remarks: The recovered specimens all conform to the neotype description of Davey and Williams (Davey et al., 1966). It can be discerned from *Hystrichosphaeridium tubiferum* by its lack of cingular processes.

Dimensions: Cyst: length: 24 (30) 43 µm; width: 21 (30) 44 µm

Processes: 11 to 24 µm

Measured: 5

Occurrences: In the Cypress Hills, *O. complex* ranges from the lower third of the Manyberries Member (chron 33n) through the middle third of the Oxarart Member (subchron 32n.2n). The species was only found in two samples in the Castor Core, in the middle Bearpaw shaly unit in subchrons 33n.2n and 33n.1n. The species was also reported from the Bearpaw Formation by Harland (1973) and Harker (1977).

It was reported from the Cenomanian and late Turonian of Alberta by Singh (1983) and Sweet and McIntyre (1988), respectively, and from the Santonian-Maastrichtian of the Northwest Territories by Ioannides (1986). *O. complex* is a long-ranging, cosmopolitan species that has been reported in sediments from the Valanginian to Oligocene (Harker et al., 1990, p. 62). Williams et al. (1993) published a geochronological range from 126 to 48 Ma.

Figured: GMUS 4262-1 013.8/105

Oligosphaeridium anthophorum (Cookson and Eisenack) Davey 1969a

Plate 7, Figure 1

1958 *Hystrichosphaeridium anthophorum* Cookson and Eisenack, p. 43, pl. 11, fig, 12.

1969 *Oligosphaeridium anthophorum* (Cookson and Eisenack) Davey, p. 147-158, pl. 5, figs. 1-3.

1982 *Stiphrosphaeridium anthophorum* (Cookson and Eisenack) Davey *in* Davey, p. 18, 35.

1985 *Stiphrosphaeridium anthophorum* (Cookson and Eisenack) Davey *in* Lentin and Williams, p. 340.

Remarks: The recovered specimens compare well with the holotype, with long tubular processes and netted, fenestrate distal terminations. The transfer of the species to the genus *Stiphrosphaeridium* by Davey (1982) that was included in Fensome and Williams (2004) is not accepted here, because, as was pointed out by Harker et al. (1990), species of *Stiphrosphaeridium* possess solid processes.

Dimensions: Cyst: length: 32 (48) 56 µm; width: 24 (33) 47 µm

Processes: 13 to 20 µm

Measured: 7

Occurrences: Specimens were recovered from the Cypress Hills section, ranging from the upper half of chron 33n in the Manyberries Member through subchron 32n.2n. It was not recovered from the Castor core. It was

reported from the Bearpaw Formation (Harland, 1973; Harker et al., 1990; Kurita and McIntyre, 1994) and from the Lea Park, Judith River and Pierre formations (Harker et al., 1990). The species was also reported from Cenomanian (Singh, 1983) and Turonian (Sweet and McIntyre, 1988) sediments of Alberta and the Campanian-Maastrichtian of the Northwest Territories by Ioannides (1986). Inferred age range: Cenomanian to Maastrichtian.

Figured: GMUS 4205-2 006.5/100.5

Oligosphaeridium pulcherrimum (Deflandre and Cookson) Davey and Williams 1966b

Plate 7, Figure 2

1955 *Hystrichosphaeridium pulcherrimum* Deflandre and Cookson, p. 270-271, pl. 1, fig.8; text-figs.21-22.

1966b *Oligosphaeridium pulcherrimum* (Deflandre and Cookson) Davey and WiIliams, p.75-76, pl. 10, fig. 9.

Remarks: The species is readily identified by its distinctive buccinate processes and elaborate distal terminations. Ioannides (1986) noted a finely granular texture on the autocyst of some of his specimens from the Northwest Territories.

Dimensions: Cyst: length: 32 (43) 53 µm; width: 32 (44) 56 µm

Processes: 13 to 24 µm

Measured: 6

Occurrences: Specimens were restricted to the Manyberries Member in the Cypress Hills section from chron 33n to 32n.3n. Specimens were found throughout much of the Bearpaw Formation in the Castor core, from subchrons 33n2n through 32n.5r. It was previously reported from the Cenomanian and Turonian of Alberta (Singh 1983; Sweet and McIntyre 1988), the Bearpaw Formation and adjacent units by Harland (1973), Harker (1977) and Kurita and McIntyre (1994), and the from the Northwest Territories by Ioannides (1986). It is known to range globally from the Valanginian to Eocene in Europe and India, but seems to have an upward limit of the Maastrichtian in other locales (Harker et al., 1990, p. 65).

Figured: GMUS 4248 A 007/114

Subfamily UNCERTAIN

Genus *Cometodinium* Deflandre and Courteville 1939

Cometodinium* cf. *whitei (Deflandre and Courteville) Stover and Evitt 1978 emend. Monteil 1991

Plate 7, Figure 3

1939 *Hystrichosphaeridium whitei* Deflandre and Courteville, p.103, p1.3, fig. 5.

1964 *Baltisphaeridium whitei* (Deflandre and Courteville) Downie and Sarjeant, p. 98.

1974 *Impletosphaeridium* sp. *cf. I. whitei* (Deflandre and Courteville) McIntyre, pl. 12, fig. 12.

1978 *?Cometodinium whitei* (Deflandre and Courteville) Stover and Evitt, p. 227.

1991 *Cometodinium whitei* (Deflandre and Courteville) Stover and Evitt emend. Monteil, p. 444, pl. 2, figs.1a-c; pl. 3, fig. 9.

Remarks: The species is identifiable by its hoary appearance and spherical to subspherical ambitus, with many fibrous processes and apical archeopyle. The neotype of Monteil (1991) possessed processes that were fibrous, but were described as "sparse" and grouped into "tufts," which is not the case in the recovered material. The recovered specimens are all spherical and are much smaller than the type material, but they do fall within the smaller sizes reported by Harker et al. (1990) who considered that the difference in size represented intraspecific variability. This difference could be the result of provincialism or endemic conditions within the Bearpaw Sea.

Dimensions: Cyst: diameter 24 (29) 40 μm

Processes: 9 to 11 μm

Measured: 9

Occurrences: Recovered specimens were restricted to the Manyberries Member of the Cypress Hills, from the upper half of chron 33n to the lower part of 32n.4n (probable identification). *C. whitei* was also reported by Singh (1983) from the Cenomanian of Alberta, Sweet and McIntyre (1988) from the late Turonian of Alberta, the Lower Campanian of the Northwest Territories (McIntyre, 1974) and from the Pierre Formation of Saskatchewan and Alberta (Harker et al., 1990). Inferred age range:

Cenomanian to Campanian.

Figured: GMUS 4352 A 011.5/112.8

Genus *Pervosphaeridium* Yun 1981

Pervosphaeridium truncatum (Davey) Below emend. Harker and Sarjeant 1990

Plate 7, Figure 4

1969 *Exochosphaeridium striolatum* (Deflandre) var. *truncatum* Davey, p. 164-166, pl. 7, fig. 1-3.

1973 *Exochosphaeridium striolatum trucatum* Davey *in* Lentin and Williams, p. 56.

1974 *Exochosphaeridium* sp. *cf. E. striolatum* Deflandre *in* McIntyre, pl. 13, figs. 5, 6.

1978 *Exochosphaeridium? truncatum* (Davey) Stover and Evitt, p. 154.

1982 *Pervosphaeridium truncatum* (Davey) Below, p. 27, pl. 5, figs. 10, 12.

1990 *Pervosphaeridium truncatum* (Davey) Below emend. Harker and Sarjeant *in* Harker, Sarjeant and Caldwell, p. 73-74, pl. 3, figs. 10-12.

Remarks: The recovered specimens conform to the emended diagnosis for the species, with fibrous periphragm, precingular archeopyle and hollow, tapering processes that are often recurved distally.

Dimensions: Cyst: length: 24 (40) 56 µm; width: 16 (36) 56 µm

Processes: 5 to 24µm

Measured: 9

Occurrences: The species was recovered solely from the Manyberries Member, Cypress Hills section from chron 33n to subchron 32n.6n. It was reported by Harker et al. (1990) from the Lea Park, Judith River and

Pierre formations of Saskatchewan and Manitoba; the Austin Chalk and Taylor Marl of Texas; and the Wapiabi Formation of Alberta. It was reported by McIntyre (1974) as *E.* cf. *striolatum* from the late Santonian to Campanian of the Northwest Territories and the original type material was reported by Davey (1969) from the Cenomanian of Texas. Known distribution: Albian to Campanian.

Figured: GMUS 4244-1 022/108

Order PERIDINALES Haeckel 1894

Suborder PERIDINIINEAE (Autonym)

Family PERIDINIACEAE Ehrenberg 1831

Subfamily DEFLANDREOIDEAE Bujak and Davies 1983

Genus *Alterbidinium* Lentin and Williams 1985

emend. Khowaja-Ateequzzaman, Garg and Jain 1991

Alterbidinium acutulum (Wilson) Lentin and Williams 1985

emend. Khowaja-Ateequzzaman, Garg and Jain 1991

Plate 7, Figure 5

1967b *Deflandrea acutula* Wilson, p. 225-226, figs. 11-12.

1967 *Albertia recticornis* Vozzhennikova, p. 151-152, pl. 77, figs. 1-4, pl. 78, fogs. 1-3, pl. 79, figs. 1, 2.

1967 *Albertia curvicornis* Vozzhennikova, p. 151, pl. 76, figs. 1-4.

1976 *Alterbia acutula* (Wilson) Lentin and Williams, p. 48, pl. 5, fig. 69.

1985 *Alterbidinium acutulum* (Wilson) Lentin and Williams, p. 11, 14.

1990 *Alterbidinium acutulum* (Wilson) Lentin and Williams *in* Harker, Sarjeant and Caldwell., p. 103-104, pl. 7, fig. 14.

1990 *Alterbidinium recticornis* (Vozzhennikova) Harker and Sarjeant *in* Harker, Sarjeant and Caldwell, p. 104.

1991 *Alterbidinium acutulum* (Wilson) Lentin and Williams emend. Khowaja-Ateequzzaman, Garg and Jain, p. 41-42, pl. 2, figs. 1-4, 7-9, text-fig. 4A-B.

Remarks: The specimens resemble the original and emended illustrations in overall shape, with a broad apical horn and two antapical horns of which the left is more developed. The overall size range of the recovered specimens are larger than the range given with the emended diagnosis, although the size range here does match that reported by Harker et al. (1990). In many specimens the endocysts were also not found within the pericysts. The emended species encompasses the species *A. curvicornis* and *A. recticornis.*

Dimensions: Pericyst: length: 53 (73) 100 µm; width: 35 (49) 87 µm
Endocyst (average): 39 - 40 µm
Measured: 11

Occurrences: Antonescu et al. (2001a) cited the first occurrence of an "*Alterbidinium* cf. *acutulum"* as being a biosignal for the C-M boundary. In the Cypress Hills section, *A. acutulum* ranges from the upper third of the Manyberries Member in subchron 32n.6n, to the top of the Thelma

Member in chron 31r. It was found in older sediments in the Castor section in subchron 33n.1r and in a second zone from subchron 32n.6n through 32n.5r.

The species was also reported by Harker et al. (1990) from the Pierre Formation of central-eastern Saskatchewan and Manitoba, and Pierre Shale of Wyoming. It was reported without illustration by Singh (1983) from the Cenomanian of Alberta. It has a reported stratigraphic range from the Turonian to Palaeocene.

Figured: GMUS 4181 007/101.8

Alterbidinium dictyotum Harker and Sarjeant

in Harker, Sarjeant and Caldwell 1990 ex Harker and Sarjeant 1991

Plate 7, Figure 6

1990 *Alterbidinium dictyotum* Harker and Sarjeant *in* Harker, Sarjeant and Caldwell, p1.8, fig. 1; text-fig.2l (nom. nud.).

1991 *Alterbidinium dictyotum* Harker and Sarjeant *in* Harker, Sarjeant and Caldwell ex Harker and Sarjeant, p. 706.

Remarks: The recovered specimens all share the distinctive reticulated pericyst ornamentation, large blunt apical horn and large size characteristic of the species. The endocysts in many of the specimens were unmeasureable or missing.

Dimensions: Pericyst: length: 61 (71) 80 µm; width: 32 (37) 42 µm

Measured: 3

Occurrences: Specimens were recovered from the upper half of the Manyberries Member in the Cypress Hills, from chron 32r through subchron 32n.4n. It was originally reported by Harker et al. (1990) from the Pierre Formation of Saskatchewan and Manitoba and from the Niobrara Formation and Pierre Shale of Wyoming. It was subsequently reported by Heine (1991) from the Campanian of Texas. The species' stratigraphic range is currently limited to the late Campanian.

Figured: GMUS 4214 A 011/103

Alterbidinium minus (Alberti) Lentin and Williams 1985

emend. Khowaja-Ateequzzaman, Garg and Jain 1991

Plate 7, Figure 7

1959 *Deflandrea minor* Alberti, p. 98, pl. 9, figs. 9-11.

1974 *Deflandrea minor* Alberti *in* McIntyre, pl. 2, figs. 4, 5.

1975 *Deflandrea minor* Alberti *in* McIntyre, p. 66, pl. 2, figs. 9, 10.

1975 *Deflandrea minor* Alberti *in* Wall and Singh, p. 1166, pl. 3, fig. 7.

1985 *Alterbidinium minor* (Alberti) Lentin and Williams, p. 14.

1989 *Alterbidinium minus* (Alberti) Lentin and Williams, p. 13.

1991 *Alterbidinium minus* (Alberti) Lentin and Williams
emend. Khowaja-Ateequzzaman, Garg and Jain, p.44.

Remarks: The recovered specimens conform well to the type material in being a circumcavate and dorso-ventrally compressed with the pentagonal

ambitus, deltaform intercalary archeopyle, broad apical horn and well-developed left antapical horn characteristic of the genus. It is distinguished from other species of *Alterbidinium* by its small size, some of which were smaller than the size range reported in the emended description of Khowaja-Ateequzzaman et al. (1991). Particularly, they resemble those illustrated by McIntyre (1975).

Dimensions: Pericyst: length: 48 (54) 56 μm; width: 32 (37) 42 μm

Measured: 4

Occurrences: Antonescu et al. (2001b) cite the first occurrence (FO) of this species as one of the key biosignals for the C-M boundary at Tercis les Bains, where it has a FO datum of 118.6 $\pm$ 3.8 m, very close to the GSSP's mean position of 115 m. The stratigraphic position of the species' FO in this study is lower than reported by them in subchron 32n.2n, increasing in abundance through the C-M boundary interval.

In the Cypress Hills, ranges from the uppermost Oxarart Member in subchron 32n.2n through the Thelma Member in chron 31r. It was not found in the Castor section. It was initially reported from Senonian strata in Germany by Alberti (1959) and New Zealand (Wilson, 1967) (most likely Campanian to Maastrichtian in age) and has been consistently reported from the late Campanian and Maastrichtian of the Northwest Territories (McIntyre, 1974, 1975; Ioannides, 1986), the Western Interior (Wall and Singh, 1975; Harker, 1977), Atlantic seaboard (i.e. Benson, 1976; Barss et al., 1979) and Europe, including

the type locality of the Maastrichtian at the ENCI Quarry in the Netherlands (Schiøler et al., 1997).

Figured: GMUS 4186 008/114.1

Alterbidinium* cf. *montanaense (Harland) Lentin and Williams 1985

Plate 7, Figure 8, 9

1977 *Deflandrea montanaensis* Harland, p. 184-185, pl. 25, figs. 4, 6, 7, 10-12.

1985 *Alterbidinium montanaense* (Harland) Lentin and Williams, p.14.

Remarks: The recovered specimens are much larger than those reported by Harland (1977) (who used the smaller size as a feature distinguishing the species from *Spinidinium*) and are therefore compared. They possess the antapical skirt and well-developed left antapical horn characteristic of *Alterbidinium* and lack the extensive denticulation found in *Spinidinium*.

Dimensions: Cyst: length: 52 (66) 80 µm; width: 29 (41) 53 µm

Measured: 12

Occurrences: Specimens were recovered in the Cypress Hills section from the upper portion of the Manyberries Member (subchron 32n.6n) to the top of the Belanger Member (chron 31r). Individuals were also recovered from the upper Bearpaw Formation and lower Horseshoe Canyon Formation in the Castor well (subchrons 32n.5r and 32n.5n). The type material was reported from the Bearpaw Formation of Montana by Harland (1977), where it ranged throughout the formation. Stratigraphic distribution: late

Campanian to Maastrichtian.

Figured: GSC 401316 009.5/95, GMUS 4189 021.5/101.8

Genus *Cerodinium* (Vozzhennikova) Lentin and Williams 1987

Cerodinium* cf. *diebelii (Alberti) Lentin and Williams 1987

Plate 8, Figure 1

1959 *Deflandrea diebelii* Alberti, p. 99-100, pl. 9, figs. 18-21.

1973 *Ceratiopsis diebelii* (Alberti) Lentin and Williams, p. 24.

1974 *Deflandrea diebelii* Alberti *in* McIntyre, pl. 4, figs. 4, 5.

1977 *Ceratiopsis diebelii* (Alberti) Lentin and Williams *in* Harland, p. 184, pl. 25, fig. 16.

1987 *Cerodinium diebelii* (Alberti) Lentin and Williams, p. 114.

Remarks: The recovered specimens are poorly preserved, with the apical horn often truncated. Many specimens are smaller in overall size than the type material. They resemble the type material in that they lack an obvious cingulum on the pericyst and the endocyst is ovoidal and fills most of the central body of the pericyst. The great variation in size could represent a continuum within *C. diebelii*, or may indicate more than one species is involved. Additional better preserved material is required to resolve this problem.

Dimensions: Pericyst: length: 56 (109) 161 μm; width: 32 (53) 74 μm

Measured: 13

Occurrences: The recovered specimens range throughout the Cypress Hills section,

from chron 33n to 31r, reaching an acme at 199.6 m in the Thelma Core (upper Manyberries Member, chron 32r, sample UofS 4268). It was only recovered from the Horseshoe Canyon Formation within the Castor Core (subchron 32n.5n).

Antonescu et al. (2001) considered the first occurrence of this species at Tercis les Bains to be a key biosignal of the C-M boundary, with the FO present in late Campanian sediments at level 76 in the Tercis section (the GSSP for the boundary is located at level 115). Schiøler et al. (1997) reported recovery of *C. diebelii* in the lower half in the ENCI Quarry in The Netherlands. In his biostratigraphy of sediments from Western Greenland, Nøhr-Hansen (1996) erected a *C. diebelii* Zone to denote the early Maastrichtian, although the actual C-M boundary interval was not present in the sections he studied due to a discontinuity. Doerenkamp et al. (1976) found the species to be numerous in their zone CVII in the Northwest Territories, which they considered to be Maastrichtian in age. Harland (1977) found the species to range from the uppermost Campanian into the Maastrichtian in the Bearpaw Formation of Montana. Williams et al. (1993) reported stratigraphic range of 86.0 to 62.0 Ma for the species in the northern hemisphere (Santonian to Danian).

Figured: GMUS 4248 A 016.5/112

Cerodinium pannuceum (Stanley) Lentin and Williams 1987

Plate 8, Figure 2

1965 *Deflandrea pannucea* Stanley, p.220, pl. 22, figs. 1-4, 8-10.

1970 *Deflandrea pannucea* Stanley *in* Zaitzeff and Cross, pl. 6, figs. 55, 56.

1974 *Deflandrea* sp. cf. *D. pannucea* Stanley *in* McIntyre, pl. 2, fig. 11.

1977 *Ceratiopsis pannucea* (Stanley) Lentin and Williams, p. 21.

1978 *Deflandrea? pannucea* Stanley *in* Stover and Evitt, , p. 101.

1987 *Cerodinium pannuceum* (Stanley) Lentin and Williams, p.115.

1990 *Cerodinium pannuceum* (Stanley) Lentin and Williams *in* Harker, Sarjeant and Caldwell, p. 108-109, pl. 7, figs. 12, 16.

Remarks: The recovered specimens conform to the type material, with their characteristically wrinkled pericyst and sub-pentagonal ambitus.

Dimensions: Pericyst: length: 73 (93) 113 µm; width: 24 (42) 60 µm

Measured: 7

Occurrences: The species was only recovered from the Cypress Hills section, from the upper half of chron 33n to 32n.4n in the Manyberries Member. Possible specimens were also identified in the upper Belanger and Thelma Members. Harker et al. (1990) reported recovery of the species from the Bearpaw Formation in Saskatchewan, the Pierre Formation of Manitoba and the Pierre Shale of Wyoming. Barss et al. (1979) reported a distribution of Maastrichtian to Palaocene in North America, which is here extended to include the late Campanian.

Figured: GMUS 4294 A 008.5/111

Cerodinium speciosum (Alberti) Lentin and Williams 1987

Plate 8, Figure 3

1959 *Deflandrea speciosa* Alberti, p.97, pl. 9, figs. 12, 13.

1977b *Ceratiopsis speciosa* (Alberti) Lentin and Williams, p. 21.

1986 *Deflandrea speciosa* (Alberti) Ioannides, p. 19, pl. 11, fig. 9

1987 *Cerodinium speciosum* (Alberti) Lentin and Williams, p.115.

Remarks: The specimens resemble material illustrated by other workers from Campanian strata. Due to their state of preservation, no attempt was made to differentiate specimens to the variety level of *speciosum* (Alberti, 1959) or *glabrum* (Gocht, 1969), in which the latter is distinguished by the presence of irregularly spaced granules or pustules on the ectophragm.

Dimensions: Pericyst: length: 40 (69) 98 µm; width: 37 (48) 60 µm

Measured: 7

Occurrences: The species is confined to the Manyberries Member in the Cypress Hills section, from the upper half of chron 33n to the top of chron 32r. It has previously been reported from the Bearpaw Formation by Kurita and McIntyre (1994) as var. *glabrum* and from Texas by Harker et al. (1990) (var. *speciosum*). The species was also reported from the Northwest Territories by Ioannides (1986) (no differentiation to subspecies). It has a known range of Campanian to Palaeocene.

Figured: GMUS 4254 B 013/108

Genus *Chatangiella* Vozzhennikova 1967

Chatangiella? biapertua (McIntyre) Lentin and Williams 1976

Plate 9, Figure 1

1975 *Deflandrea biapertua* McIntyre, p. 66, pl. 3, fig. 5-6.

1976 *Chatangiella? biapertua* (McIntyre) Lentin and Williams, p. 53.

Remarks: The recovered specimens resemble the holotype in general form, with large spherical endocyst adpressed with the pericyst equatorially, the presence of an identifiable cingulum and in the possession of two openings: the omega-hexaform intercalary archeopyle and an opisthopyle between the antapical horns. They differ from the type material in that several smaller forms were recovered. They seem to conform in size to the specimens illustrated by Kurita and McIntyre (1994, pl. 4.1, figs. 5 and 6).

Dimensions: Cyst: length: 53 (82) 110 µm; width: 37 (47) 156 µm

Measured: 10

Occurrences: Specimens were recovered from throughout the Cypress Hills section, ranging from chron 33n in the Manyberries Member to chron 31r in the Thelma Member. The species was also reported by Kurita and McIntyre (1994) from the Bearpaw Formation in the Bow River section and foothills of Alberta. It was first reported by McIntyre (1975) from Maastrichtian strata in the Northwest Territories. Known age range:

Campanian to Maastrichtian.

Figured: GSC 401316 010/91

Chatangiella decorosa (McIntyre) Lentin and Williams 1976

Plate 9, Figure 3

1975 *Deflandrea decorosa* McIntyre, p. 63-64, pl. 2, fig. 1-4.

1976 *Chatangiella decorosa* (McIntyre) Lentin and Williams, p. 54.

Remarks: The recovered specimens closely resemble the type material, with pustules decorating the pericyst. A round endocyst dominates the cingular region, the cingulum being discernible in most specimens by groups or ridges of pustules. The omegaform archeopyle is broad and often an operculum remains attached on its lower margin. It differs from *C. ditissima* in being larger and usually sporting more pustules (McIntyre, 1974, p. 64).

Dimensions: Pericyst: length: 81 (110) 139 μm; width: 48 (61) 74 μm

Endocyst: length: 40 to 60 μm

Measured: 17

Occurrences: The species occurs in two zones within the Cypress Hills section, in the lower part of the Manyberries Member in chron 33n and in the Belanger and Thelma members (subchrons 32n.1n through 31r). A similar partitioning was found to occur in the Castor section, in subchron 33n.1r in the Bearpaw Formation and in subchrons 32n.5r to 32n.5n in the Bearpaw transition and Horseshoe Canyon Formation.

The species was first reported by McIntyre (1974, 1975) from the Campanian-Maastrichtian of the Northwest Territories. Kurita and McIntyre (1994) also reported the species from the Bearpaw Formation of Alberta. It was reported by Harker et al. (1990) from the Lea Park and Judith River formations of Saskatchewan and Pierre Formation of Manitoba, and from the Campanian of the Labrador Shelf by Barss et al. (1979). Known age range: Campanian to Maastrichtian.

Figured: GMUS 4185 013/116

Chatangiella ditissima (McIntyre) Lentin and Williams 1976

Plate 9, Figure 4

1975 *Deflandrea ditissima* McIntyre, p. 62-63, pl. 1, figs. 1-2.

1975 *Deflandrea victoriensis* Cookson and Manum *in* Wall and Singh, p. 1166, pl. 3, fig. 5.

1976 *Chatangiella ditissima* (McIntyre) Lentin and Williams, p. 54.

Remarks: The observed specimens conform to the type material, with the exception of being smaller, a trait that was also observed by Harker et al. (1990). The species differs from *Chatangliella decorosa* in being smaller overall and possessing narrower shoulders, a more adpressed endocyst and fewer pustules. It differs from *Chatangiella victoriensis* in being somewhat larger, possessing a broad omegaform archeopyle and lacking extensive ornament on the endocyst.

Dimensions: Pericyst: length: 60 (90) 120 μm; width: 32 (48) 64 μm

Endocyst length: 34 to 44 μm

Measured: 23

Occurrences: The species was found to range throughout the Cypress Hills section, from the Manyberries Member (chron 33n) through the Thelma Member (chron 31r). It was limited to subchron 33n.1r in the Bearpaw Formation in the Castor section.

It was also reported from the Bearpaw Formation of Saskatchewan by Harker (1977) and Harker et al. (1990), and Alberta by Kurita and McIntyre (1994). It was also reported by Harker (1977) in the Lea Park, Judith River and Pierre formations of Saskatchewan and Manitoba. Harker et al. (1990) also posited that the specimens identified by Wall and Singh (1975) from the Buffalo Head Hills of Alberta as *C. victoriensis* are in fact *C. ditissima.* It was also identified by Sweet and McIntyre (1988) from the Turonian of Alberta.

It has a known range of upper Santonian to lower Maastrichtian in the Canadian Arctic (McIntyre, 1974, 1975; Doerenkamp et al., 1976; Ioannides, 1986) and Turonian to Maastrichtian in Alberta.

Figured: GMUS 4498 A 017/107

Chatangiella granulifera (Manum) Lentin and Williams 1976

Plate 9, Figure 5

1963 *Deflandrea granulifera* Manum, p.61-64, pl.3, figs. 5-9.

1976 *Chatangiella granulifera* (Manum) Lentin and Williams, p. 54.

Remarks: The recovered specimens resemble the type material in possessing a coarse, granular ornament on the pericyst and endocyst. The endocyst is usually adpressed to the pericyst and a cingular girdle is normally visible. Many of the recovered specimens are smaller than the size range reported by Manum (1963).

Dimensions: Pericyst: length: 53 (75) 97 µm; width: 40 (52) 64 µm

Average endocyst: 37 x 52 µm

Measured: 8

Occurrences: Specimens were recovered exclusively from the upper part of the Cypress Hills section from the upper Manyberries Member (subchron 32n.4r) to the Thelma Member (chron 31r). The species was also reported from the Bearpaw Formation by Harland (1973) and the Lea Park and Pierre Formations of Saskatchewan and Manitoba by Harker (1977). It was reported from the Turonian of Alberta by Sweet and McIntyre (1988) and from the late Santonian to Campanian of the Canadian Arctic (McIntyre, 1974; Ioannides, 1986) and from Greenland by Nøhr-Hansen (1996).

Known distribution: Turonian to Maastrichtian. Harker et al. (1990) suggested that this species was characteristic of cold waters.

Figured: GSC 401315 022/85

Chatangiella spectabilis (Alberti) Lentin and Williams 1976

Plate 9, Figure 2

1959b *Deflandrea spectabilis* Alberti, p. 99, pl. 9, figs.7, 8.

1976 *Chatangiella spectabilis* (Alberti) Lentin and Williams, p. 54.

Remarks: The recovered specimens resemble those reported from the Bearpaw Formation by Harland (1973), including being of a more diminutive size than reported from the type material. A similar size range was reported by Ioannides (1986).

Dimensions: Pericyst: length: 56 (72) 85 µm; width: 32 (45) 63 µm

Endocyst average: 40 x 45 µm

Measured: 13

Occurrences: *Chatangiella spectabilis* occurs throughout the Cypress Hills section, although a hiatus was noted from the uppermost Manyberries Member to the Belanger Member (subchrons 32n.4n to 32n.1r). It was not recorded in the Castor core.

In addition to the report of Harland (1973) the species has been recovered from the Bearpaw, Lea Park, Judith River and Pierre formations of Saskatchewan and Manitoba by Harker (1977) and Harker et al. (1990). Wall and Singh (1975) reported it in their "Bearpaw Flora" from the Buffalo Head Hills of Alberta and Sweet and McIntyre (1988) reported the species from the Turonian of Alberta. It has also been reported from the late Santonian to Maastrichtian of the Arctic

(McIntyre 1974, 1975; Ioannides, 1986).

Figured: GMUS 4189 020.3/101

Chatangiella tripartita (Cookson and Eisenack) Lentin and Williams 1976

1960 *Deflandrea tripartita* Cookson and Eisenack, p. 2-3, pl. 1, fig. 10

1976 *Chatangiella tripartita* (Cookson and Eisenack) Lentin and Williams, p. 54.

Plate 10, Figure 1

Remarks: This species is distinctive in its ambitus, consisting of a broad shouldered epipericoel with blunt horn, a large spherical endocyst and a skirt-like hypopericoel which extends distally in a short left antapical horn.

Dimensions: Pericyst: length: 89 (92) 95 µm; width: 39 (46) 53 µm

Endocyst average dimension: 57 x 46 µm

Measured: 2

Occurrences: The recovered specimens are restricted solely to the Belanger Member in the Cypress Hills section (subchron 32n.1n). It was also reported from the Bearpaw Formation of Alberta by Harland (1973) and from the Bearpaw, Lea Park, Judith River of Saskatchewan and Pierre formations of Manitoba and Wyoming by Harker (1977) and Harker et al. (1990) and the Campanian of Texas by Heine (1991). The species ranges throughout the Late Cretaceous, from the Turonian to the Maastrichtian.

Figured: GMUS 4278 A 006/164

Chatangiella turbo Harker and Sarjeant *in* Harker, Sarjeant and Caldwell

ex Harker and Sarjeant 1991

Plate 10, Figure 2

1990 *Chatangiella turbo* Harker and Sarjeant *in* Harker, Sarjeant and Caldwell, p. 118-120, pl. 9, figs. 5-8; text-fig. 23 nom. nud.

1991 *Chatangiella turbo* Harker and Sarjeant *in* Harker, Sarjeant and Caldwell ex Harker and Sarjeant, p. 709.

Remarks: The species is distinctive in its relatively large size, spindle-shaped ambitus and hexaform archeopyle. The species was invalid as first erected in Harker et al. (1990) as no location was specified for the lodgement of the holotype in contravention of the International Code of Botanical Nomenclature. This was subsequently rectified by Harker and Sarjeant (1991).

Dimensions: Pericyst: length: 69 (91) 105 µm; width: 39 (46) 53 µm

Endocyst average dimension: 57 x 46 µm

Measured: 4

Occurrences: The species was identified from the lower Manyberries Member (chron 33n) in the Cypress Hills section. It was not recovered from the Castor core. It was identified by Harker et al. (1990) in the Lea Park and Pierre formations of Saskatchewan and Manitoba.

Figured: GMUS 4498 A 017/115

Genus *Eucladinium* Stover and Evitt 1978

Eucladinium spinosissimum (Cookson and Eisenack) Stover and Evitt 1978

Plate 10, Figure 3

1970 *Deflandrea spinosissimum* Cookson and Eisenack, p. 141, pl.11, fig. 5-6.

1978 *Eucladinium spinosissimum* (Cookson and Eisenack) Stover and Evitt, p. 104.

Remarks: Recovered specimens are circumcavate, with the apical pericoel more obvious and ending in a short, blunt horn. Antapical horns are absent. Ornamentation is present on the periphragm in the form of small bumps on the epicyst. The only paratabulation that is evident is the intercalary archeopyle and a weakly-defined cingulum.

Dimensions: Cyst: length: 39 (52) 64 μm; width: 24 (44) 64 μm

Measured: 8

Occurrences: Specimens were recovered from the Manyberries Member in the Cypress Hills section from chron 33n to subchron 32n.4r. It was recovered from the Castor well in subchron 33n.1n. It was previously reported from the Bearpaw Formation by Kurita and McIntyre (1994). Its known distribution is from the Campanian and Maastrichtian (Fensome and Williams, 2004).

Figured: GSC 401346 019/80

Genus *Isabelidinium* Lentin and Williams 1977a

Isabelidinium korojonense (Cookson and Eisenack) Lentin and Williams 1977a

Plate 11, Figure 1

1958 *Deflandrea korojonensis* Cookson and Eisenack, p.27-28, pl. 4, fig. 10-11.

1976 *Isabelia korojenensis* (Cookson and Eisenack) Lentin and Williams, p. 56.

1977a *lsabelidinium korojonensis* (Cookson and Eisenack) Lentin and Williams, p.167.

1985 *Isabelidinium korojenense* (Cookson and Eisenack) Lentin and Williams, p. 200 (orthographic change).

Remarks: The species is identifiable by its quadrangular ambitus, smooth pericyst, truncated apex and round to rounded polygonal archeopyle. The size range of the specimens recovered conforms to the range reported by Harland (1973).

Dimensions: Pericyst: length: 73 (93) 113 µm; width: 35 (50) 64 µm
Endocyst: 32 (45) 58 µm long x 48 (56) 64 µm wide
Measured: 13

Occurrences: The species was found to be restricted to the Manyberries Member in the Cypress Hills section (chron 33n to subchron 32n.4n). It was reported previously from the Bearpaw Formation (Harland, 1973; Harker et al., 1990) and coeval Late Cretaceous strata from Saskatchewan and Manitoba. It was also reported from Campanian – Maastrichtian sediments from offshore Atlantic Canada (Barss et al., 1979). Known range: Campanian to Maastrichtian.

Figured: GMUS 4224 B 011.8/113

Isabelidinium acuminatum (Cookson and Eisenack) Stover and Evitt 1978

Plate 11, Figure 2

1958 *Deflandrea acuminata* Cookson and Eisenack, p. 47, pl. 4, figs. 5-8.

1978 *Isabelidinium acuminatum* (Cookson and Eisenack) Stover and Evitt, p. 109.

Remarks: The recovered specimens have a free endocyst that ranges in shape from ovoidal to nearly spherical. A weakly defined cingulum is usually visible at the equatorial margin of the pericyst.

Dimensions: Pericyst: length: 50 (65) 81 µm; width: 32 (47) 61 µm

Endocyst: 31 (34) 37 µm long x 24 (43) 60 µm wide

Measured: 8

Occurrences: The species has been recovered from late Santonian to Maastrichtian strata in the Northwest Territories (McIntyre, 1974; Ioannides, 1986) and western Greenland (Nohr-Hansen, 1996). It was reported from the Lea Park, Judith River, Upper White-Speckled Shale and Pierre formations of Saskatchewan and Manitoba (Harker, 1977; Harker et al., 1990) and the late Turonian of Alberta (Sweet and McIntyre, 1988). It was also reported from Campanian to Maastrichtian strata of Texas (Zaitzeff and Cross, 1970; Heine, 1991). It has a known range from the Cenomanian to Danian (Barss et al., 1979).

Figured: GMUS 4205-1 012/113.5

Isabelidinium belfastense (Cookson and Eisenack) Lentin and Williams 1977a

Plate 11, Figure 4

1961 *Deflandrea belfastense* Cookson and Eisenack, p.71, pl. 11, figs. 4-6.

1977a *Isabelidinium belfastense* (Cookson and Eisenack) Lentin and Williams, p. 167.

Remarks: The species is identified by its vertically-elongated pericyst, blunt horns, the absence of a visible cingulum and an ovoidal endocyst that is usually free floating. The recovered specimens conform well to the type material from Australia.

Dimensions: Pericyst: length: 72 (105) 137 μm; width: 35 (48) 61 μm

Endocyst: 31 (39) 48 μm long x 24 (31) 39 μm wide

Measured: 9

Occurrences: Specimens were recovered only from the Cypress Hills section, with intermittent occurrences in the Manyberries Member (chron 33n to subchron 32n.3r) and from the Belanger to Thelma Member (subchrons 32n.1n, 31r). The species was reported previously from the Bearpaw Formation in Alberta by Kurita and McIntyre (1994) and from the Late Cretaceous of the Northwest Territories (McIntyre, 1974; Doerenkamp et al., 1976; Ioannides, 1986). It was reported from the Campanian of Texas by Heine (1991). It ranges from the Santonian to Maastrichtian.

Figured: GMUS 4185 008/102.8

Isabelidinium* cf. *cooksoniae (Alberti) Lentin and Williams 1977a

Plate 11, Figure 3

1959 *Delflandrea cooksoni* Alberti, p.97, p1.9, figs. 1-6.

1970 *Delflandrea cooksoni* Alberti *in* Zaitzeff and Cross, pl. 5, fig. 10.

1973 *Australiella cooksoni* (Alberti) Lentin and Williams, p. 18.

1976 *Isabelia cooksoniae* (Alberti) Lentin and Williams, p. 57, pl. 8, fig. 110.

1977a *Isabelidinium cooksoniae* (Alberti) Lentin and Williams, p. 167.

1994 *Isabelidinium* sp. Kurita and McIntyre, p. 74, pl. 4.1, figs 8, 9.

Remarks: This species is identifiable by its round archeopyle, usually adpressed subspherical endocyst, blunt horns and lack of a cingulum. The periphragm is normally ornamented with a granular texture. Kurita and McIntyre (1994) reported a species similar to *I. cooksoniae* from the Bearpaw Formation that lacked this ornamentation, which they also likened to the specimens of *Chatangiella spectabilis* recovered by Harland (1973). As the amount of granulation was found to vary on the recovered specimens, it is possible that specimens of *Isabelidinium* sp. *sensu* Kurita and McIntyre's description were included in the counts of this species, and thus the population recovered here are compared to the species as described by Alberti (1959).

Dimensions: Pericyst: length: 53 (75) 97 µm; width: 32 (52) 72 µm

Endocyst: 24 (44) 64 µm long x 32 (48) 64 µm wide

Measured: 13

Occurrences: The species occurs intermittently in the Cypress Hills and Castor

sections. In the Cypress Hills, it occurs in the Manyberries Member from 33n to 32n.3r and then undergoes a hiatus to the Belanger Member (32n.1n to 31r). In the Castor well it is found within the Bearpaw strata in subchrons 33n.2r and 33n.1r, the Bearpaw transition zone in subchron 32n.5r and the Horseshoe Canyon Formation in subchron 32n.5n.

It has been reported from the late Santonian to Maastrichtian of the Northwest Territories (McIntyre, 1974; Ioannides, 1986) and western Greenland (Nohr-Hansen, 1996). It was identified in late Turonian strata from Alberta (Sweet and McIntyre, 1988) and from the Coniacian to Maastrichtian in sediments from offshore Atlantic Canada (Barss et al., 1979). Harker (1977) and Harker et al. (1990) reported the species from the Lea Park, Judith River and Pierre formations of Saskatchewan and Manitoba, and from the Pierre Shale of Wyoming. It has an age range of Turonian to Danian (Harker et al., 1990, p. 123).

Figured: GMUS 4242-1 013/107.5

Isabelidinium microarmum **(**McIntyre) Lentin and Williams 1977a

Plate 12, Figure 9

1975 *Deflandrea microarma* McIntyre, 1975, pl. 1, figs. 5-8.

1977a *Isabelidinium microarmum* (McIntyre) Lentin and Williams, p.168.

Remarks: This species is identifiable by its small shoulders on the epipericyst, which are not as pronounced as in *Chatangiella,* and in possessing a

large, rounded hexagonal intercalary archeopyle. A cingulum is not present. The shoulders may also be ornamented by spines. Most specimens are larger than *I. cooksoniae,* from which it can also be differentiated by the shoulders, longer left antapical horn and shape of the archeopyle.

Dimensions: Pericyst: length: 64 (85) 105 µm; width: 48 (68) 89 µm

Endocyst: 32 to 48 µm long (5 specimens)

Measured: 10

Occurrences: The species occurs intermittently in the lower part of the Manyberries Member (chron 33n) and in the Belanger Member (32n.1r to 31r) in the Cypress Hills section. It was found in the Castor well in Bearpaw strata in subchron 33n.1r and in the transition zone in subchron 32n.5r. It was first reported from the Campanian of the Northwest Territories by McIntyre (1975) and subsequently by Ioannides (1986) from the Campanian and Maastrichtian of the Arctic Archipelago. It was also reported from the mid – late Campanian of western Greenland (Nohr-Hansen, 1996) and the Campanian – Maastrichtian of Texas (Heine, 1991). It has a published age range of Campanian to Maastrichtian (Fensome et al., 1998).

Figured: GMUS 4278 A 012/105.4

Genus *Senegalinium* Jain and Millepied 1973 emend. Stover and Evitt 1978

Senegalinium bicavatum Jain and Millepied 1973

Plate 11, Figure 5

1973 *Senegalinium bicavatum* Jain and Millepied, p. 23, pl. 1, figs. 1-4, text-fig. 1B.

Remarks: The recovered material conforms well to the type material, consisting of a cavate pericyst dominated almost entirely by a spherical endocyst, leaving three equally developed horns (1 apical, 2 antapical) formed by pericoels. The cingulum is indistinct, although Jain and Millepied (1973) did report a clearer sulcus on the ventral side of the cyst. No other paratabulation was reported.

Dimensions: Pericyst: length: 54 (70) 85 µm; width: 45 (51) 56 µm

Endocyst: 48 to 56 µm long

Measured: 6

Occurrences: The species is confined to the Cypress Hills section, from the Manyberries Member (chron 33n) to the lower Oxarart Member (subchron 32n.2n). It has a known age range of Campanian to Maastrichtian (Fensome et al., 1998).

Figured: GMUS 4224 A 017.4/108

Senegalinium obscurum **(**Drugg) Stover and Evitt 1978

Plate 11, Figure 6

1967 *Deflandrea obscurum* Drugg, p. 17, pl. 2, figs. 8-9, pl. 9, fig. 5.

1978 *Senegalinium obscurum* (Drugg) Stover and Evitt, p. 123.

Remarks: The species is larger than *S. bicavatum* and the antapical horns are unequally developed. An indication of paratabulation can be seen and the cingulum is fairly distinct. The recovered specimens are somewhat larger than the type material but this is considered to be infraspecific variation.

Dimensions: Pericyst: length: 40 (63) 85 µm; width: 32 (44) 56 µm

Endocyst: 26 (44) 61 µm long

Measured: 15

Occurrences: The species was recovered from the Cypress Hills section, ranging through the Manyberries Member and from the Belanger Member to the Thelma Member (32n.1n and 31r). McIntyre (1974) reported it as *"Deflandrea'* cf. *obscura"* from the Northwest Territories. Ioannides (1986) reported the occurrence of *Senegalinium macrocysta* and a form cf. *S. microgranulatum* from the Canadian Arctic. The type material has a range from the Maastricthian to Danian. Williams et al. (1994) published a range for the genus from the mid-Campanian to the Oligocene.

Figured: GMUS 4236 A 016/106

Genus *Spinidinium* Cookson and Eisenack 1962 emend. Lentin and Williams 1976

Spinidinium clavus Harland 1973

Plate 12, Figure 1

1973 *Spinidinium clavum* Harland, p. 674-675, p1.84, figs. 5-6, 10; text-fig. 9.

1981 *Spinidinium clavus* Harland *in* Lentin and Williams, p. 257.

Remarks: The recovered specimens conform well to the type material except for having a greater range in size.

Dimensions: Cyst: length: 24 (48) 72 µm; width: 16 (36) 56 µm

Measured: 18

Occurrences: The species is common in the Cypress Hills core, ranging throughout the entire section (chrons 33n to 31r). In the Castor well it appears to be confined to the lower part of the Bearpaw Formation, from subchrons 33n.2r through 33n.1n.

It was first reported by Harland (1973) from the Bearpaw Formation in the Lethbridge area and was also identified by Kurita and McIntyre (1994) from the Bearpaw Formation around Calgary. The species was reported by Harker et al. (1990) from the Lea Park, Judith River, Bearpaw and Pierre formations of Saskatchewan and Manitoba, and the Pierre Shale of Wyoming. Heine (1991) reported it from the Campanian – Maastrichtian of central Texas. It has been reported from the late Santonian to Maastrichtian of the Northwest Territories (McIntyre 1974; Doerenkamp et al., 1976) and from western Greenland (Nøhr-Hansen, 1996). Its known distribution is late Santonian to Danian.

Figured: GMUS 4220 A 015/99.6

Spinidinium echinoideum (Cookson and Eisenack emend. Sverdlove and Habib) Lentin and Williams 1976

Plate 12, Figure 2

1960a *Deflandrea echinoidea* Cookson and Eisenack, pl. 2, p1.l, figs.5-6.

1974 *Deflandrea echinoidea* Cookson and Eisenack emend. Sverdlove and Habib, p. 58-59, pl. 1, figs. 1-6, text-figs. 2a-b.

1976 *Spinidinium echinoideum* (Cookson and Eisenack) emend. Sverdlove and Habib *in* Lentin and Williams, p. 146.

1978 *Vozzhennikovia echinoideum* (Cookson and Eisenack) Stover and Evitt, p.130.

1980 *Spinidinium echinoideum* (Cookson and Eisenack) Lentin and Williams *in* Lentin and Williams, p. 20, 22, 24.

Remarks: The recovered specimens conform to the type material and differ from *S. clavum* in possessing more pronounced dense, echinate spines that are not limited to paraplate boundaries.

Dimensions: Cyst: length: 45 (63) 81 μm; 32 (44) 56

Measured: 5

Occurrences: Specimens were limited to the Cypress Hills section, where they were recovered from the Manyberries Member (upper part of chron 33n through subchron 32n.4r), with one specimen also identified in the Thelma Member (chron 31r).

The species was also reported from the Bearpaw Formation of Alberta by Harland (1973) and from the Lea Park Formation of Saskatchewan

and Pierre Formation of Manitoba by Harker et al. (1990). It was also reported from the Campanian-Maastrichtian of Texas (Harker et al., 1990; Heine 1991), western Greenland (Nøhr-Hansen, 1996) and the late Turonian of Alberta (Sweet and McIntyre, 1988). Known stratigraphic range: Turonian to Maastrichtian.

Figured: GMUS 4220 B 013/108

Genus *Trithyrodinium* Drugg 1967 emend. Lentin and Williams 1976

Trithyrodinium evittii Drugg 1967

Plate 12, Figure 3

1967 *Trithyrodinium evittii* Drugg, p.20, p1.3, figs. 2-3, pl. 9, fig. 2.

1969 *Trithyrodinium fragile* Davey, p. 11-12, pl. 3, fig. 3, 6, 9.

1986 *Trithyrodinium fragile* Davey *in* Ioannides, p. 39, pl. 20, figs. 10, 12, 17, 21, 22.

1999 *Trithyrodinium evittii* Drugg *in* Nøhr-Hansen and Dam, p. 129.

Remarks: The species is identified by its operculum-free combination archeopyle and thick, naked endocyst – the fragile pericyst subject to being torn away. The recovered cysts were poorly preserved were normally smaller than *T. suspectum*. The specimens recovered here conform in size to those figured as *T. fragile* by Ioannides (1986), which was considered by Nøhr-Hansen and Dam (1999, p. 129) to be a taxonomic junior synonym of *T. evittii*.

Dimensions: Endocyst: length: 32 (48) 64 µm; width: 32 (43) 53 µm

Measured: 15

Occurrences: The species was recovered from the upper two-thirds of the Manyberries Member (33n to 32n.3r) and from the Thelma Member (31r) in the Cypress Hills section.

Trithyrodinium evittii has been used by several workers in the past to denote the basal Maastrichtian. For that reason, Antonescu et al. (2001b) considered the first occurrence of *T. evittii* to be one of the 19 candidate dinoflagellate biosignals in the C-M boundary interval at Tercis les Bains. However, it was not cited in the final definition of the GSSP as a key biosignal as it was found to enter the succession there between 74.0 m and 80.6 m (Antonescu et al., 2001b, p. 256 and fig. 2). This observation, coupled with the report by Kurita and McIntyre (1994) of *T. evittii* from the upper part of the Bearpaw Formation near Calgary, the recovery of *T. fragile* (=*T. evittii)* by Ioannides (1986) from Campanian strata in the Canadian Arctic and the observations in this study would suggest that the species' biostratigraphic significance may not be as great as previously believed. Williams et al. (1993) report a range of 98.0 to 59.0 Ma for the genus in the northern hemisphere.

Figured: GMUS 4186 018.5/110.5

Trithyrodinium suspectum (Manum and Cookson) Davey

emend. Lentin and Williams 1976

Plate 12, Figure 4

1964 *Hexagonifera suspectum* Manum and Cookson, p. 9-10, pl.1, figs. 9-13.

1969 *Trithyrodinium suspectum* (Manum and Cookson) Davey, p. 12.

1976 *Trithyrodinium suspectum* (Manum and Cookson) Davey

emend. Lentin and Williams, p. 98-100.

Remarks: The species is larger than *T. evittii* and possesses a granulate texture on the endophragm. As with other members of the genus, the pericyst is very fragile and is frequently subject to loss. Owing to the poor state of preservation of both species it is possible that individual specimens may be incorrectly assigned to either species.

Dimensions: Cyst: length: 54 (60) 66 µm; width: 45 (47) 50 µm

Measured: 3

Occurrences: The species was recovered intermittently and in a poor state of preservation in the Cypress Hills section, from the lower Manyberries Member (chron 33n) and possibly from the top of the Thelma Member (chron 31r). It was not recovered from the upper Manyberries, Oxarart or Belanger members. It was also reported from the late Turonian Cardium Formation of Alberta by Sweet and McIntyre (1988), from western Greenland (Nøhr-Hansen, 1996) and the Campanian - Maastrichtian of the Canadian Arctic (Ioannides, 1986.) Williams et al. (1993) report a range of 98.0 to 59.0 Ma for the genus in the northern hemisphere.

Figured: GMUS 4352 A 011/102

Subfamily Ovoidinioudeae (Norris) Bujak and Davies 1983

Genus *Leberidocysta* Stover and Evitt 1978

Leberidocysta chlamydata (Cookson and Eisenack) Stover and Evitt 1978

Plate 12, Figure 5

1962 *Hexagonifera chlamydata* Cookson and Eisenack, p.496, pl.7, figs. 1-3, 5-8.

1978 *Leberidocysta chlamydata* (Cookson and Eisenack) Stover and Evitt, p. 59.

1984 *Polygonifera chlamydata* (Cookson and Eisenack) Mehrota and Sarjeant, p. 46.

1985 *Leberidocysta chlamydata* (Cookson and Eisenack) Stover and Evitt *in* Lentin and Williams, p. 214.

Remarks: The recovered specimens compare well with the type material and specimens recovered by Ioannides (1986), consisting of a thick-walled verrucose endocyst within an ephemeral hyaline pericyst. The endoarcheopyle is apical. The pericyst is often finely reticulate.

Dimensions: Pericyst: length: 42 (52) 77 µm; width: 39 (45) 64 µm
Endocyst: length: 27 (38) 48 µm; width: 23 (35) 48 µm
Measured: 10

Occurrences: The species occurs in the Manyberries Member in the Cypress Hills (33n to 32n.5n) and from the middle Bearpaw Formation (32r) and lower Horseshoe Canyon Formation (32n.5n) in the Castor core. The species was originally reported from the Cenomanian of Australia (Cookson and Eisenack, 1962), subsequently being reported from the Santonian – Campanian of the Canadian Arctic (McIntyre, 1974; Ioannides 1986), and the Turonian of Alberta (Sweet and McIntyre,

1988). Williams et al. (1993) report a stratigraphic range from the Albian to mid-Campanian (108 to 78 Ma). It was reported by Schiøler et al. (1997) from the base of the Maastrichtian type section at the ENCI Quarry in The Netherlands, suggesting that the age range of the species is Albian to Early Maastrichtian.

Figured: GSC 401326 007/87

Subfamily PALAEOPERIDINIOIDEAE (Vozzhennikova 1961)
Bujak and Davies 1983

Genus *Laciniadinium* McIntyre 1975

Laciniadinium arcticum (Manum and Cookson) Lentin and Williams 1980

Plate 12, Figure 6

1964 *Diconodinium arcticum* Manum and Cookson, p.18-19, p1.6, figs. 1-4

1980 *Laciniadinium arcticum* (Manum and Cookson) Lentin and Williams, p. 46.

Remarks: The recovered specimens conform to the type material. It can be differentiated from *L. biconiculum* by the asymmetrical ambitus of the epicyst and hypocyst. The apical process is more weakly developed than in *L. firmum.* An antapical process may be present as a papilla or absent entirely.

Dimensions: Cyst: length: 37 (57) 77 μm; width: 32 (40) 48 μm

Measured: 10

Occurrences: The species ranges throughout the Cypress Hills (chron 33n to 31r) and

Castor sections (chron 33n to subchron 32.5r). It was also reported from the late Turonian Cardium Formation (Sweet and McIntyre, 1988) and Bearpaw Formation of Alberta (Harland, 1973; Kurita and McIntyre, 1994) and Saskatchewan, as well as the Judith River Formation near Saskatoon (Harker et al., 1990). It is best known from the late Cretaceous of Arctic of Canada (Manum and Cookson, 1964; McIntyre, 1974; Doerenkamp et al., 1976; Ioannides, 1986) and Greenland (Nøhr-Hansen, 1996). It has also been reported from the Campanian – Maastrichtian of Texas (Harker et al., 1990; Heine, 1991). It has a known range from the Cenomanian to Maastrichtian.

Figured: GMUS 4349 A 016.2/114.2

Laciniadinium biconiculum McIntyre 1975

Plate 12, Figure 7

1975 *Laciniadinium biconiculum* McIntyre, p.71, pl. 4, figs. 5-9.

Remarks: The recovered specimens exhibit the nearly symmetrical top-shaped ambitus characteristic of the type material, with apical and antapical processes more weakly defined than in *L. firmum*. Some specimens were also seen to possess the slash-like archeopyle, formed by a combination of 3 intercalary and 3 precingular plates.

Dimensions: Cyst: length: 37 (54) 74 µm; width: 26 (38) 53 µm

Measured: 10

Occurrences: The recovered specimens range throughout the upper two-thirds of the Manyberries Member in the Cypress Hills section and from chron 33n.2n to 32n.5r with the Bearpaw strata in the Castor core. The species has been reported from the Arctic (McIntyre, 1975; Doerenkamp et al., 1976) and from Saskatchewan, Manitoba and Wyoming (Harker et al., 1990). It may be characteristic of colder waters (Harker et al., 1990, p. 132). It appears to have a range from the late Santonian to Late Campanian.

Figured: GMUS 4268 012.5/112

Laciniadinium firmum (Harland) Morgan 1977

Plate 12, Figure 8

1973 *Diconodinium firmum* Harland, p.669-670, p1.84, figs.8-9, 15, text-fig. 6.

1975 *Diconodinium firmum* Harland *in* Wall and Singh, p. 1166, pl. 3, fig. 9

1977 *Laciniadinium firmum* (Harland) Morgan, p. 136.

Remarks: The recovered specimens conform to the type material, especially with regards to the well developed process on the apex and sharp acuminate antapical horn. The hypocyst is often narrower than the epicyst. The archeopyle appears to be a combination of intercalary and precingular plates.

Dimensions: Cyst: length: 32 (56) 81 µm; width: 24 (33) 42 µm
Measured: 18

Occurrences: The species occurs throughout the Cypress Hills section, and in the Bearpaw portion (subchrons 33n.2r through 33n.1n) and transition zone (32n.5r) of the Castor well. The species was first described by Harland (1973) from the Bearpaw Formation in Alberta and subsequently also identified by Wall and Singh (1975) and Kurita and McIntyre (1994) from the same strata. It was also reported from Saskatchewan, Manitoba, Wyoming and Texas by Harker et al (1990). It appears to be limited in range to the Campanian – Maastrichtian.

Figured: GSC 401360 021.5/107

Genus *Palaeoperidinium* (Deflandre 1934) Sarjeant 1967b

Palaeoperidinium pyrophorum (Ehrenberg ex O. Wetzel) Sarjeant 1967b

Plate 13, Figure 1

1838 *Peridinium pyrophorum* Ehrenberg, pl. 1, figs. 1, 4.

1933 *Peridinium pyrophorum* Ehrenberg ex. O. Wetzel, p. 164-165, pl. 2, figs. 12, 13.

?1934 *Peridinium* cf. *pyrophorum* Ehrenberg ex O. Wetzel *in* Deflandre, p. 967, text-fig. 1.

1955 *Palaeoperidinium pyrophorum* (Ehrenberg ex O. Wetzel) W. Wetzel, p. 407-408, pl A., fig. 10.

1966 *Peridinium conicum* (Gran) Deflandre, p. 3-4, pl. 1, figs. 1-6.

1967 *Peridinium basilium* Drugg, p. 13, pl. 1, figs. 9-11.

1967b *Palaeoperidinium pyrophorum* (Ehrenberg ex O. Wetzel) Sarjeant, p. 246-247, figs. 1-6.

Remarks: The recovered specimens have the distinctive pentagonal ambitus and large size characteristic of this species. Ornamentation in the forms of striations and pustules may be present on the periphragm. The endocyst is usually closely adpressed to the pericyst.

Dimensions: Cyst: length: 81 (140) 200 μm; width: 56 (117) 177μm

Measured: 17

Occurrences: This species is ubiquitous throughout the studied sections (from 33n to 31r). It was also reported from the Bearpaw Formation by Harland (1977), Harker et al., (1990) (in addition to coeval strata in Saskatchewan, Manitoba and Wyoming) and Kurita and McIntyre (1994). It has been reported from the Arctic (McIntyre 1974, 1975; Doerenkamp et al., 1976; Ioannides, 1986) and from offshore Atlantic Canada (Barss et al., 1979). Its known range is Turonian to Danian.

Figured: GMUS 4228 A 010/112.4

Palaeoperidinium cretaceum (Pocock ex Davey) emend. Lentin and Williams 1976

Plate 13, Figure 2

1962 *Palaeoperidinium cretaceum* Pocock, p. 80, pl. 14, fig. 219-221 nom. nud.

1970 *Astrocysta cretacea* Pocock ex Davey, p. 359-360, pl. 2, fig. 4

1973 *Lejeunia ampla* Harland, p. 673-674, pl. 84, figs. 1, 7.

1973 *Astrocysta manumcooksoni* Corradini, p. 176-177, pl. 28, figs. 4, 6.

1976 *Palaeoperidinium cretaceum* (Pocock ex Davey) emend. Lentin and Williams, p. 110.

1976 *Palaeoperidinium amplum* (Harland) emend. Lentin and Williams, p. 109.

1978 *Palaeoperidinium cretaceum* Pocock *in* Stover and Evitt, p. 218.

1990 *Palaeoperidinium cretaceum* (Pocock ex Davey) emend. Lentin and Williams *in* Harker, Sarjeant and Caldwell, p. 128-130, pl. 10, figs. 4-8, 12.

Remarks: The recovered specimens exhibit the characteristics of the type material, being smaller than *P. pyrophorum*, more elongated with sharper antapical horns and often displaying a scabrate or punctuate ornamentation on the periphragm. The name was invalidly published by Pocock (1962) and Singh (1964) as the generic name had not yet been validly published. *Lejeunia ampla* Harland, described from the Bearpaw Formation, is considered to be a taxonomic junior synonym (Harker et al., 1990, p. 128) as is *Astrocysta manumcooksoni* (Lentin and Williams, 1976b, p. 110).

Dimensions: Cyst: length: 48 (85) 121 µm; width: 37 (71) 105 µm
Measured: 23

Occurrences: The species is quite common throughout both of the studied sections. It was also reported from the Bearpaw Formation of Alberta by Harland (1973) and from Saskatchewan and Manitoba by Harker et al. (1990). It was also reported from the Cenomanian and Turonian of Alberta (Singh,

1983; Sweet and McIntyre, 1988) and from the Late Cretaceous of the Arctic (Doerenkamp et al., 1976) and as far south as Texas (Harker et al., 1990; Heine 1991). Its known range in North America is from the Barremanian to Maastrichtian (Harker et al., 1990).

Figured: GMUS 4242 A 019.5/120

Palaeoperidinium parvum (Harland) Lentin and Williams 1976

Plate 13, Figure 3

1973 *Lejeunia parva* Harland, p. 672-673, pl. 84, figs. 3, 12-14, text-fig. 7.

1976 *Palaeoperidinium parvum* (Harland) Lentin and Williams, p. 108, 110, pl. 14, fig. 221.

Remarks: The recovered material conforms to the type material, being much smaller, more elongated in ambitus and with sharper antapical horns than other species of *Palaeoperidinium.*

Dimensions: Cyst: length: 35 (46) 56 µm; width: 24 (38) 52 µm

Measured: 18

Occurrences: The species occurs throughout the Castor and Cypress Hills sections (chron 33n to 31r). It was first reported by Harland (1973) from the Bearpaw Formation in Alberta and subsequently by Kurita and McIntyre (1994). It was reported from the Bearpaw Formation of Saskatchewan and underlying strata by Harker (1977) and Harker et al. (1990). It has a known range from Campanian to Maastrichtian.

Figured: GMUS 4278 A 018/109

Family PROTOPERINIACEAE Bujak and Davies 1983

Subfamily PROTOPERIDINIOIDEAE

Genus *Phelodinium* Stover and Evitt 1978 emend. Mao and Norris 1988

Phelodinium magnificum (Stanley) Stover and Evitt 1978

Plate 13, Figure 4

1965 *Deflandrea magnifica* Stanley, p.218-219, p1.20, figs. 1-6.

1976 *Lejeunia magnifica* (Stanley) Lentin and Williams, p. 71, pl. 10, fig. 150.

1977 *Senegalinium magnificum* (Stanley) Harland, p. 188, pl. 25, fig. 2.

1978 *Phelodinium magnificum* (Stanley) Stover and Evitt, 1978, p. 118.

Remarks: The species is distinctive in its large size, with pronounced apical and antapical horns.

Dimensions: Cyst: length: 97 (150) 203 µm; width: 81 (126) 72 µm

Measured: 11

Occurrences: Specimens were only recovered from the Manyberries Member in the Cypress Hills section (chrons 33n to 32n.4r). It was reported from the Bearpaw of Montana by Harland (1977), Alberta by Kurita and McIntyre (1994) and Saskatchewan by Harker et al. (1990). It was reported from Campanian – Maastrichtian strata in Texas (Zaitzeff and Cross, 1966; Heine 1991) and from Campanian – Palaeocene sediments from North America (Barss et al., 1979). Harker et al. (1990) considered reports from the Eocene of Belgium suspect (p. 135). Inferred range:

Campanian to Palaeocene.

Figured: GMUS 4352 A 020.5/107

Phelodinium tricuspe (O. Wetzel) Stover and Evitt 1978

Plate 14, Figure 1

1933 *Peridinium tricuspis* O. Wetzel, p.166, pl.2, fig. 14.

1963 *Lejeunia kozlowskii* Górka, p. 41, pl. 5, fig. 4 nom. nud.

1970 *Astrocysta tricuspis* (O. Wetzel) Davey, p. 360.

1973 *Lejeunia tricuspis* (O. Wetzel) Harland, p. 673, pl. 84, fig. 4.

1977 *Senegalinium tricuspis* (O. Wetzel) Harland, p. 188-189, pl. 25, figs. 3, 5.

1978 *Phelodinium tricuspe* (O. Wetzel) Stover and Evitt, p. 118.

Remarks: The form is readily identified by its pentagonal ambitus, wide cingulum and sharply pointed apical and antapical horns. The specific name *P. tricuspe* is assigned to these specimens over *P. kozlowskii* as Harker and Sarjeant (1975) considered them to be conspecific, with *P. tricuspe* being the taxonomically senior synonym, notwithstanding the retention of *P. kozlowskii* by Lindgren (1984) and other subsequent workers. The distinction used by Górka (1963) to differentiate the two species is considered to be highly subjective, namely that in *P. kozlowskii* "the posterior edge of the hypotheca, which reunites at the antapical horns is less curved than in *[P.] tricuspis* (sic)" (p. 41, translated from the French – hence the nom. nud. of the original description as new species must be described in Latin or English in accordance with the I.C.B.N).

Dimensions: Cyst: length: 61 (83) 105 µm; width: 47 (60) 72 µm

Measured: 7

Occurrences: The species has been reported from the Bearpaw of Montana by Harland (1977) (as *"Senegalinium" tricuspis*) and Alberta by Kurita and McIntyre (1994) (as *P. kozlowskii).* It was also reported from the Campanian of the Northwest Territories (as *P. kozlowskii)* (McIntyre, 1975; Doerenkamp et al. 1976) and Texas (as *P. tricuspe)* (Heine, 1991).

It was found to range throughout the Cypress Hills section, with a hiatus noted during the time of deposition of the Oxarart and Belanger members (subchrons 32n.3r – 32n.1n). It was confined to the Bearpaw strata in the Castor well, in subchron 33n.1r. Stratigraphic range: Campanian – Maastrichtian.

Figured: GMUS 4236 A 013/100.2

Genus UNCERTAIN

Dinoflagellate sp. 1

Plate 14 Figures 2, 3

Description: Bicavate cyst, rounded polygonal to nearly fusiform in ambitus and ventrally flattened, consisting of a rhomboidal endocyst ensheathed closely within a thin, diaphanous pericyst that extends into one apical horn and two antapical horns, of which the left horn is much more well-developed. Paratabulation is indicated on the endocyst and equatorial

margin of the pericyst by wide laevorotary cingulum. Endoarcheopyle possibly intercalary or combination apical-intercalary which appears to remain attached along its posterior margin. A trapezoidal periarcheopyle may be present at the base of the apical horn. Sulcus only indicated by gap in cingulum on ventral side. Both periphragm and endophragm thin, subject to crumpling, folding and fracture.

Remarks: The specimens recovered most closely resemble the genus *Senegalinium* Jain and Millepied in possessing a lambda-form bicavate cyst with an apical and nearly symmetrical antapical horns, but differ from the genus in possessing a well-defined cingulum and possibly a combination apical-intercalary archeopyle. It differs from the genus *Senoniasphaera* Clarke and Verdier in lacking a distinctively notched apical archeopyle and from *Imbatodinium* Vozzhennikova in being bicavate and more rhomboidal than fusiform. It differs from *Odontochitina singhii* Morgan in possessing much shorter apical and left antapical horns, a rhomboid endocyst, distinct cingulum and lacking a definitely apical archeopyle. It also differs from *Odontochitnopsis* Eisenack in lacking an apical opercular archeopyle and possessing a closely adpressed endocyst and definite cingulum and sulcus. They are considered to be deflandroid peridineaceans.

Dimensions: Pericyst: length: 64 (89) 113 μm; width: 32 (43) 53 μm

Endocyst: 38 (60) 81 μm

Measured: 6

Occurrences: Specimens were very common in samples collected from the Manyberries locality at the base of the Bearpaw Formation just above the Lethbridge Coal Zone. They were not identified in either the Thelma or Castor cores. This horizon is late Campanian in age and a date of 75 Ma has been reported for this approximate horizon by Eberth and Deino (2005).

Figured: GMUS 4490 A021/116, GMUS 4490 A 010/115

5.2 ACRITARCH SYSTEMATICS

Classification of acritarchs has been limited to the generic level and follows Fensome et al. (1990).

Incertae sedis 'Group' ACRITARCHA Evitt, 1963

Genus *Cymatiosphaera* O. Wetzel 1933 emend. Deflandre 1954

***Cymatiosphaera?* sp. A. *sensu* Harland 1973**

Plate 15, Figure 1

1973 *Cymatiosphaera* sp. A. Harland, p. 706, pl. 88, fig. 8.

Remarks: The specimens measured vary considerably in size, but resemble the specimen figured by Harland (1973) possessing a subrounded vesicle and short, simple processes joined at the bases by septa that create polygonal fields on the autophragm that are a typical characteristic of the genus. It differs from *C. radiata* (O. Wetzel) emend. Sarjeant and *C.* cf. *radiata* identified by Harker et al. (1990) in that a reticulum formed

by membranous septa between the lengths of the processes is not present. This lack of raised septa does however raise the question of whether this form should actually be within the genus *Cymatiosphaera* or if it should be assigned to an acanthromorphid genera instead. Fensome et al. (1990) considered the genus to be a prasinophyte alga.

Dimensions: Vesicle: length: 24 (37) 48 µm; width: 24 (42) 54 µm

Processes: 5 to 16 µm

Measured: 4

Occurrences: Specimens were recovered from the upper half of the Manyberries Member in the Cypress Hills section (chron 33n to subchron 32n.3r). They were not present in the Castor well.

Figured: GMUS 4254 A 008/106

Genus *Fromea* Cookson and Eisenack 1958 emend. Yun 1981

Although treated as a dinoflagellate genus by many workers (i.e. McIntyre, 1974; Ioannides, 1986; Harker et al., 1990; Kurita and McIntyre, 1994; Nøhr-Hansen, 1996), their affinity to the dinoflagellates has always been suspect. It is uncertain if research has using biomarkers proves or disproves their affinity to the dinoflagellates (q.v. Moldowan et al., 2000). The genus was placed within the acritarchs by Fensome (Fensome et al., 1990; Fensome and Williams, 2004).

Fromea amphora Cookson and Eisenack 1958

Plate 15, Figure 2

1958 *Fromea amphora* Cookson and Eisenack, p. 56, pl. 5, figs. 10, 11.

Remarks: The recovered specimens conform to the type material, consisting of a simple ovoidal vesicle with apical pylome. An equatorial girdle (paracingulum?) was reported on the holotype and on specimens recovered by Harker et al. (1990), suggesting that the form may be polyspecific, with the 'girdled' forms possibly being a dinoflagellate cyst.

Dimensions: Cyst: length: 34 (53) 72 µm; width: 16 (28) 40 µm

Measured: 7

Occurrences: Specimens were only recovered from the Manyberries Member in the Cypress Hills section (chron 33n to subchron 32n.4n). It was reported from the Bearpaw Formation and coeval strata of Saskatchewan and Manitoba (Harker et al., 1990), the Northwest Territories (McIntyre, 1994), Greenland (Nøhr-Hansen, 1996), Cenomanian-Turonian of Alberta (Singh, 1983; Sweet and McIntyre, 1988) and the Campanian of Texas (Zaitzeff and Cross, 1970; Harker et al., 1990). Known range: ?Valanginian to Campanian, possibly early Maastrichtian.

Figured: GMUS 4214 A 008.3/104

Fromea chytra (Drugg) Stover and Evitt 1978

Plate 15, Figure 3

1967 *Palaeostomocystis chytra* Drugg, p. 35, pl. 6, fig. 12

1978 *Fromea chytra* (Drugg) Stover and Evitt, p. 48

Remarks: Vesicles are relatively small, ovoidal vesicles with a granular texture. The pylome is apical, often with an operculum still attached.

Dimensions: Cyst: length: 19 (37) 54 µm; width: 19 (43) 31 µm

Measured: 5

Occurrences: The species was recovered in the Cypress Hills section from the upper half of the Manyberries Member to the Thelma Member (chrons 32n.2n to 31r). They were to the lower Bearpaw strata in the Castor core (subchrons 33n.2r to 33n.1n). The species is quite ubiquitous, having been reported from the Northwest Territories (i.e. McIntyre, 1974; Doerenkamp et al., 1976; Ioannides, 1986) and Greenland (Nøhr-Hansen, 1996). It has been recovered from the Bearpaw Formation of Saskatchewan, as well as from coeval strata in the Canadian prairies (Harker et al., 1990) and Texas (*ibid*.; Zaitzeff and Cross, 1966). It has a known range of late Cenomanian to Maastrichtian, possibly Danian.

Figured: GMUS 4272 A 019/114

Fromea fragilis (Cookson and Eisenack) Stover and Evitt 1978

Plate 15, Figure 4

1962 *Palaeostomocystis fragilis* Cookson and Eisenack, p.496-497, pl. 7, figs.l0-l1

1978 *Fromea fragilis* (Cookson and Eisenack) Stover and Evitt, p. 48

Remarks: The recovered forms conform to the type material and previous reports in all respects, consisting of large elongate ovoid vesicles with a distinctive longitudinal fold and possessing an apical, operculum-free pylome.

Dimensions: Vesicle: length: 72 (102) 156 µm; width: 29 (47) 64 µm

Measured: 7

Occurrences: Specimens were found to range throughout the Cypress Hills and Castor sections (chrons 33n to 31r). It has been recovered from the Albian to Campanian of the Northwest Territories (McIntyre, 1974; Doerenkamp et al., 1976; Ioannides, 1986) and the Cenomanian-Turonian of Alberta (Singh, 1983; Sweet and McIntyre, 1988). It has been recovered from the Bearpaw Formation of Alberta (Kurita and McIntyre, 1994) and Saskatchewan, as well as coeval strata in the Canadian prairies (Harker et al., 1990) and Texas (Harker et al., 1990; Heine, 1991). It has a known range from the Albian to Danian.

Figured: GMUS 4244-1 015/112

Genus *Michrystridium* Deflandre 1937 emend. Staplin 1961

***Michrystridium harlandii* Harker and Sarjeant *in* Harker, Sarjeant and Caldwell ex Harker and Sarjeant 1991**

Plate 15, Figure 5

1973 *Michrystridum* sp. A Harland, p. 696, pl. 88, figs. 2, 3.

1990 *Michrystridium harlandii* Harker and Sarjeant *in* Harker, Sarjeant and Caldwell, p. 145, pl. 12, figs. 4, 7, 8, 16, 17; text-figs 2, 3 nom. nud.

1991 *Michrystridium harlandii* Harker and Sarjeant *in* Harker, Sarjeant and Caldwell ex Harker and Sarjeant, p. 702.

Remarks: The recovered specimens closely resemble the form first reported by Harland (1973) from the Bearpaw Formation near Lethbridge, Alberta with the species erected by Harker and Sarjeant (Harker et al., 1990). The original description was invalid as it did not provide the site of lodgement of the holotype, in contravention of the I.C.B.N. It was subsequently rectified in Harker and Sarjeant (1991). The form is distinguished by its subspherical vesicle with shagreenate ornamentation and approximately 10 thin, solid spines that arise from hollow bases on the vesicle.

Dimensions: Cyst: length: 16 (19) 22 μm; width: 16 (17) 19 μm

Processes: 8 to 19 μm

Measured: 4

Occurrences: The species was found to range from the upper Manyberries Member into the Thelma Member (32n.4r to 31r) in the Cypress Hills section. It

was first reported as *Michrystridium* sp. A by Harland (1973) from the Bearpaw Formation near Lethbridge and subsequently by Harker and Sarjeant from the Lea Park, Judith River, Bearpaw and Pierre formations from Saskatchewan and Manitoba, as well as the Wapiabi and Clagget formations of Alberta, the Niobrara Formation and Pierre Shale of Wyoming, and the Austin Chalk and Taylor Marl of Texas (Harker et al., 1990, p. 146). Known distribution: late Santonian to Maastrichtian.

Figured: GSC 401338 009.5/96.8

Michrystridium spp.

Plate 15, Figure 6

Remarks: Other forms that could be assigned to the genus, but were either too poorly preserved or too few in number were not identified to the species level. They consist of spherical to subspherical vesicles with 15 or more solid spines, some of which are joined at their bases by septa or hollow protrusions.

Dimensions: Vesicle: diameter: 15 (24) 32 µm

Processes: 8 to 16 µm

Measured: 15

Occurrences: Specimens occur intermittently throughout the Manyberries and Oxarart members of the Cypress Hills section (33n to 32n.2n), and in the middle and upper Bearpaw strata of the Castor core (33n.2r to 32n.6r).

Figured: GSC 401343 004.5/97

Genus *Veryhachium* Deunff 1954 emend. Sarjeant and Stancliffe 1994

***Veryhachium* spp.**

Plate 15, Figure 8

Remarks: Forms possessing the characteristic polygonal ambitus terminating in 3 to 9 hollow processes, within a size range of 15 to 50 μm were collectively placed within this genus. No formal attempt was made to classify the recovered forms to the species level owing to their scarcity and often poor preservation. Forms include vesicles with two or three alternating arrays of 3 processes, each array occupying a separate focal plane (c.f. *V. trisulcum* Deunff ex Downie emend. Loeblich and Tappan), and forms with 3 or 4 processes in the same focal plane (c.f. *V. rhomboidium* Downie and *V. cruciatum* (O. Wetzel) emend. Lejeune-Carpentier and Sarjeant).

Dimensions: Vesicle (including processes): length: 11 (27) 32 μm;
width: 16 (32) 48 μm
Measured: 10

Occurrences: Specimens were found to range from the upper half of the Manyberries Member through the Belanger Member (chron 32r to 31r) in the Cypress Hills section. Only a few specimens were recovered from the Bearpaw sediments in the Castor core, from subchrons 33n.1r and 32n.5r.

Figured: GMUS 4216-1 009.9/112

Algae Incertae Sedis

Genus *Palambages* O. Wetzel 1961

Palambages morulosa Gocht and Wille 1972

Plate 15, Figure 9

1961 "Morulosae" O. Wetzel, p. 23-14, pl. 4, figs. 1-5.

1971 *Palambages* Form A Singh, p. 429-430, pl. 80, figs. 5, 6.

1972 *Palambages morulosa* Gocht and Wille, p. 146, text figs. 1-24.

1974 *Palambages* Form A McIntyre, pl. 13, fig. 12.

1974 *Palambages* Form C McIntyre, pl. 13, fig. 11.

1986 *Palambages spp.* Ioannides, p. 42, pl. 24, figs. 3, 13, 16; pl. 25, figs. 7, 8.

1990 *Palambages morulosa* O. Wetzel *in* Harker, Sarjeant and Caldwell, p. 149-150, pl. 13, figs. 10-12.

Remarks: The form is extremely distinctive, consisting of even-numbered clusters of closely packed spherical vesicles. The re-examination of the type material by Gocht and Wille (1972) and subsequent diagnosis of *P. morulosa* is sufficiently broad as to encompass the variety of forms described by other workers. Harker et al. (1990) considered *Palambages* to be a chlorophyte algal colony.

Dimensions: Cyst/Colony?: diameter: 43 (82) 120 μm

Individual spherule: 10 to 50 μm

Measured: 14

Occurrences: Specimens were recovered throughout the Cypress Hills section (magnetozones 33n to 31r) and from the Bearpaw strata within the Castor well (subchrons 33n.2r to 32n.5r), possibly suggesting an environmental preference. The species has been previously reported as different forms from the Santonian to Maastrichtian of the Northwest Territories (McIntyre, 1974; Doerenkamp et al., 1976; Ioannides, 1986) and from the Turonian of Alberta (Sweet and McIntyre, 1988). The species was reported from the Bearpaw, Lea Park, Upper White Speckled-Shale and Pierre formations of Saskatchewan and Manitoba by Harker (1977) and Harker et al. (1990), with an inferred age range of Albian to Palaeocene (*ibid*., p. 150).

Figured: GMUS 4490 A 008/116.5

6.0 PALYNOLOGICAL OBSERVATIONS AND DISCUSSION

6.1 GENERAL

A total of 34 genera and 69 species of dinoflagellate cysts and 8 forms of acritarchs were identified in the Cypress Hills and the RCA Castor core. In total, 21 633 palynomorphs were counted, of which 4510 were identified as dinocysts and 626 as acritarchs. The remainder were broadly identified as bisachate pollen, other spores and pollen (including angiosperm pollen, and trilete and monolete spores and megaspores) and specimens of the genus *Aquilapollenites.* Possible fungal spores, algal cells, foraminiferal linings and scolecodont elements were also noted, as well as the overall preservation of the sample and the presence of plant tissue, charcoal and inertinite. This latter category was used only to provide a qualitative context for the samples' general state of preservation, degree of terrestrial influx and the effects of maceration on the sample and was not rigorously analyzed.

6.2 PALYNOSTRATIGRAPHY

6.2.1 Relative Abundance

Results of the counts were plotted against the depth of the sample and correlated against the magnetostratigraphy of Lerbekmo and Braman (2002) and Lerbekmo et al. (2003). The relative abundance of each species in a sample was calculated by taking the percentage of that species from the total number of dinocysts and acritarchs counted within the sample and assigning one of the following letter grades:

- Abundant (A) if the count was greater than 25 %;

- Common (C) if the count was between 5 and 25 %;
- Infrequent (I) if the count was between 1 and 5 %; and
- Rare (R) if the count was less than 1 %.

The relative abundances of specimens are recorded in Figure 6.1 for the Cypress Hills section and Figure 6.2 for the Castor section.

6.2.2 Assemblage Composition

The assemblages recovered in this study closely resemble those reported by Harland (1973), Wall and Singh (1975) and Kurita and McIntyre (1994) from Bearpaw strata at other localities in Alberta. Both the Cypress Hills and Castor assemblages are dominated by peridinialean cysts, conforming to the boreal McIntyre Suite posited by Lentin and Williams (1980) due to their preponderance of cavate and proximate peridinialean cysts, particularly species of *Chatangiella* and *Laciniadinium.* The assemblages depart to some degree from the strict definition of the McIntyre Suite in the prevalence of *Palaeoperidinium* –the most prevalent genus in both sections – and the strong showing of *Isabelidinium, Spinidinium* and *Alterbidinium.* This suggests that the McIntyre Suite in Alberta is affected by warmer prevailing conditions, making it less boreal than the original definition of the suite *sensu stricto*, based as it was primarily on reports from the Northwest Territories and Canadian Arctic Archipelago.

Gonyaulacacean cysts are also present in lower numbers, especially cosmopolitan genera such as *Spiniferites, Hystrichosphaeridium, Oligosphaeridium, Odontochitina, Spongodinium, Microdinium* and *Downiesphaeridium*. The recovery of dinogymnoids was low in both sections, particularly in the Cypress Hills.

Figure 6.1: Range chart showing relative abundance of microplankton taxa recovered from the Cypress Hills section, correlated against the magnetostratigraphy of Lerbekmo and Braman (2002). Biozonation described in section 6.5 of text. Key: *Abundant (A), count > 25 %; Common (C), count between 5 and 25 %; Infrequent (I), count between 1 and 5 %; Rare (R), count < 1 %. 'Med'=Medicine Lodge Member.*

| Stage | | |

Figure 6.2: Range chart showing relative abundance of microplankton taxa recovered from the Castor section, correlated against the magnetostratigraphy of Lerbekmo et al. (2003). Biozonation described in section 6.5 of text. Key: *Abundant (A), count > 25 %; Common (C), count between 5 and 25 %; Infrequent (I), count between 1 and 5 %; Rare (R), count < 1 %.*

| Stage | | | | | | | | CAMPANIAN | | | | | | | |

6.2.3 Taxa Recovered from the Cypress Hills Section

Dinocysts and acritarchs made up between 6.9 % and 49 % (mean 28 %) of the palynomorphs recovered in the samples from the RCA Thelma core and the outcrop near Manyberries, Alberta. Diversity, in terms of species per sample, was highest in the Manyberries Member from chron 33n to the end of subchron 32n.4r (Figure 6.3). All of the reported species occur within the Cypress Hills section. Peridinialean taxa were most prevalent, with four genera each exceeding 10 % of taxa recovered. The most prevalent taxa are listed in Table 6.1.

Table 6.1: Prevalence of selected dinoflagellate genera from the Cypress Hills section of Alberta

Peridinoid Genera	Prevalence (%)
Palaeoperidinium	13.6
Laciniadinium	12.1
Chatangiella	10
Isabelidinium	10
Spinidinium	4.2
Alterbidinium	4
Cerodinium	3.7
Senegalinium	3.3
Dinoflagellate sp. 1	1.6
Trithyrodinium	1.0
Gonyaulacoid Genera	
Microdinium	5.6
Spiniferites	4
Oligosphaeridium	2.9
Hystrichosphaeridium	2.8
Downiesphaeridium	2.8
Spongodinium	2.6
Odontochitina	2.3
Dinogymnoid Genera	
Dinogymnium	0.5

The most common peridinialean species found include *Palaeoperidinium cretaceum* (282 specimens), *Laciniadinium arcticum* (234 specimens), *Isabelidinium* cf. *cooksoniae* (222 specimens), *L. firmum* (215 specimens), *P. parvum* (198 specimens),

Chatangiella ditissima (169 specimens), *Spinidinium clavus* (139 specimens) and *Chatangiella? biapertua* (113 specimens). Gonyaulacaceans recovered in large numbers include *Microdinium* cf. *ornatum* (231 specimens), *Spongodinium delitiense* (106 specimens including fragments), *Odontochitina operculata* (94 specimens including isolated horns), *Gonyaulacysta* cf. *eisenackii* (88 specimens) and *Spiniferites ramosus* (82 specimens). The most common of the very scarce dinogymnoid taxa was *Dinogymnium acuminatum* (7 specimens). Amongst the incertae sedis and acritarchs recovered, *Palambages morulosa* and *Fromea fragilis* were the most common with 254 and 156 specimens recovered, respectively.

6.2.4 Taxa Recovered from the RCA Castor Core

The dinocysts and acritarch assemblage recovered from the Castor well was much less diverse than from the Cypress Hills section, with much higher terrestrial influx evidenced by higher concentrations of spores and pollen, phytoclast debris, charcoal and inertinite. The recovery of dinocysts and acritarchs compared to the total palynoflora counted ranged from 0.29 % to 19.6 % (mean 8.3 %), with a total of 41 species of dinocysts and 6 acritarchs recovered. The assemblage with the highest number of species recovered was found in the transitional marine zone between the upper shale unit of the Bearpaw Formation and the Horseshoe Canyon Formation in subchron 32n.5r (Figure 6.4). However, with only 20 species identified in this sample, this maximum is only half that of the most diverse assemblage from the Cypress Hills.

As in the Cypress Hills, the Castor assemblage was dominated by species of *Palaeoperidinium* and *Laciniadinium*, with species of *Chatangiella* a more distant third. *Downiesphaeridium* was the most prevalent gonyaulacacean genus, followed by

Oligosphaeridium, Circulodinium and *Microdinium*. Table 6.2 lists the most prevalent genera.

The most common species in the assemblage included peridinialeans *Palaeoperdinium cretaceum* (49 specimens), *Laciniadinium arcticum* (48 specimens), *Laciniadinium firmum* (31 specimens), *Palaeoperidinium parvum* (21 specimens), *Chatangiella decorosa* (14 specimens) and *Alterbidinium acutulum* (13 specimens). The most common gonyaulacacean species were *Downiesphaeridium armatum* (15 specimens), *Oligosphaeridium pulcherrimum* (14 specimens), *Odontochitina operculata* (14 specimens), *Circulodinium distinctum* (13 specimens) and *Microdinium* cf. *ornatum.* Both *Spiniferites ramosus* and *Spongodinium delitiense* were minor constituents of the assemblage, with 5 specimens of each species recovered. As in the Cypress Hills section, *Palambages morulosa* (33 specimens) and *Fromea fragilis* (28 sepcimens) were the most common acritarch forms.

In sharp contrast to the Cypress Hills material, species of *Dinogymnium* were far more prevalent, accounting for 4.7 % of the recovered dinocysts. This large difference may be due to environmental conditions at the time of deposition, but may also be due to taphonomic factors or even differences in sample processing between GSC Calgary and the University of Saskatchewan Palynology Laboratory. A similar situation can be seen in the higher prevalence of *Circulodinium distinctum* within the Castor well, particularly in the lower shale unit, ranging from subchrons 33n.2r through 33n.1r.

Table 6.2: Prevalence of selected dinoflagellate genera from the RCA Castor borehole

Peridinoid Genera	Prevalence (%)
Palaeoperidinium	22
Laciniadinium	20.7
Chatangiella	6.5
Alterbidinium	4.2
Isabelidinium	4.2
Spinidinium	2
Gonyaulacoid Genera	
Downiesphaeridium	6
Oligosphaeridium	4
Odontochitina	3.5
Microdinium	3.2
Circulodinium	3.2
Dinogymnoid Genera	
Dinogymnium	4.7

6.2.5 Index Species

Three of the ten dinocyst taxa previously reported from the Bearpaw Formation and coeval strata as well as from the C-M boundary stratotype at Tercis les Bains (Antonescu et al. 2001a, 2001b; Schiøler and Wilson, 2001) were recovered in this study. They include: *Odontochitina operculata, Alterbidinium minor* and *Trithyrodinium evittii.* A fifth significant taxon, *Cerodinium diebelii,* is also compared to forms recovered in the current succession as *Cerodinium* cf. *diebelii.* The taxon, stratigraphic signal – first occurrence (FO) or last occurrence (LO) –level within the Tercis succession and location and magnetostratigraphic position recovered in the present study are listed in Table 6.3. While not identified as biosignals at Tercis, the species *Dinogymnium acuminatum* (= *Gymnodinium kazachstanium* of Vozzhennikova, 1967 which she considered to be diagnostic of the Campanian) and *Spongodinium delitiense* (considered an index taxon by Williams and Bujak, 1985) also have their LO's within Campanian strata in this study.

The ranges of these and other selected taxa are shaded in the Cypress Hills section and from the RCA Castor core in Figure 6.1 and Figure 6.2, respectively. Magnetostratigraphic ranges of all taxa recovered in the study are listed in Chapter 5, Systematic Palaeontology.

Table 6.3: List of index taxa, with their stratigraphic locations at Tercis les Bains and magnetostratigraphic locations in the Cypress Hills and Castor cores. Magnetostratigraphy adapted from Lerbekmo and Braman (2002), Lerbekmo et al. (2003). GSSP position is 115 m (Odin and Lamaurelle, 2001).
MB=Manyberries Member, OX=Oxarart Member, Thel=Thelma Member, HC=Horseshoe Canyon Formation, N/R=not reported

Taxon	Signal	Tercis Interval (m) (Antonescu et al., 2001b)	Cypress Hills Section	Castor Section
Odontochitina genus	LO	78.3 ± 2.3 33n	MB, 32n.4r, Thel 135.6 m	Upper Sh, 32r, 50.0 m
Alterbidinium minor	FO	118.6 ± 3.8 ~32n.3n	OX, 32n.2n, Thel 65.5 m	N/R
Trithyrodinium evittii	FO	79.0 ± 0.6 33n	MB, 33n, Thel 278.3 m	N/R
Cerodinium diebelii	FO	70.5 ± 5.5 33n	As cf.: MB 33n, Thel 300.0 m	HC, 32n.5n 8.5 m
Dinogymnium acuminatum	LO	N/R	MB, 32n.3r, Thel 106.8 m	Upper Sh, 32n.6n, 37.5 m
Spongodinium delitiense	LO	N/R	MB, 32n.3r, Thel 106.8 m	Upper Sh, 32n.6n, 37.5 m

The biosignals of the LO data for the Campanian index taxa *Odontochitina operculata, Dinogymnium acuminatum* and *Spongodinium delitiense* all within chron 32n and the FO data and increase in abundances of *Alterbidinium minor* and *A. acutulum* with the base of chron 31r support the location of the Campanian-Maastrichtian boundary with the 32n-31r transition as defined for the global stratotype by Lewy and Odin (2001) and

Antonescu et al. (2001b) at Tercis les Bains and postulated by Lerbekmo and Braman (2002) for the Western Interior of North America.

6.3 PALAEOENVIRONMENTAL INDICATORS

6.3.1 Diversity and Dominance

In addition to assessing relative abundance of species within the assemblage, semi-quantitative assessments were made of the diversity and dominance within the assemblage in each sample by plotting the number of dinocyst species per sample and the number of dinocysts per sample. A high number of species suggests a diverse assemblage, particularly when combined with a high number of cysts per sample which suggests optimal conditions within the succession. A low number of species but high number of cysts suggests a more marginal environment, dominated by a few species. A low number of species and dinocysts suggest a restricted environment, in which only a limited number of taxa can survive.

6.3.2 Relative Abundance as Indicator of Terrestrial Influx

The degree of terrestrial influx was assessed by calculating the ratio of dinocysts to spores and pollen (D:S). A high value is indicative of a higher proportion of dinocysts and is interpreted as distal and more openly marine conditions, while a comparatively low value due to high concentration of terrestrial material suggests a proximal environment dominated by terrestrial influx. Typically, workers have used ratio of terrestrial sporomorphs to dinocysts (or S:D ratio) (i.e. Harland, 1973; Li and Habib, 1996). However, high terrestrial influx in the Castor well obscured some of the features of the S:D ratio, making observation of trends difficult, particularly in the lower part of the

section. Thus, both ratios were calculated and plotted versus the magnetostratigraphic column and were found to show inverse trends.

6.3.3 G:P Ratio

Wall and Dale (1967) first demonstrated the utility of using the ratio of gonyaulacacean (G) to peridinoid (P) species to assess environmental conditions in Recent sediments, based on the observation that gonyaulacacean taxa are more prevalent in open marine conditions, whereas peridinoid species tend to dominate more marginal inshore and estuarine environments. The G:P ratio for an assemblage collected from a deep sea core was calculated as 18.0, whereas sediments collected from a near-shore locality at Woods Hole, Massachusetts yielded an assemblage with a G:P ratio of 0.44. Harland (1973) first applied the concept of the G:P ratio to the assemblages he recovered from the Lethbridge and Cypress Hills sections of the Bearpaw Formation. It has since been used as an assessment of palaeoproductivity, particularly in Quaternary sediments (i.e. Wall et al., 1977; Veerstegh, 1994; Dale, 1996; Reichart and Brinkhuis, 2003; Sluijs et al., 2005), predicated on the observation that the motile forms of modern gonyaulacaceans are predominantly autotrophic, while peridinoid cyst-forming taxa are predominantly heterotrophic. Gonyaulacoid forms prefer more open marine conditions that facilitate photosynthesis and diurnal migration through the water column, whereas heterotrophic peridinoids thrive in areas where potential sources of food, such as diatoms, are more plentiful and can thus frequent habitats with lower light levels and more marginal conditions.

The G:P ratio, as utilized by Harland (1973), is based on the number of species of each group. Other authors (i.e. Veerstegh, 1994; Harris and Tocher, 2003; Kumar and

Patterson, 2002) have used ratios based on the relative numbers of individual specimens. To assess the difference between these two approaches, G:P ratios were calculated for species ($G:P_{sp}$) and individual cysts ($G:P_{ind}$) to assess both the relative dominance of these two morphological groups within the succession as well as the difference between the two ratios. In both cases, a value >1.25 in both the Cypress Hills and Castor sections suggests a flora dominated by autotrophic gonyaulacacean cysts, while a value <1.25 indicates a flora dominated by presumably heterotrophic peridinialean cysts. Plots of the G:P ratios, dinoflagellate species per sample, dinocysts per sample and the D:S and S:D ratios are illustrated in Figure 6.3 for the Cypress Hills section and Figure 6.4 for the Castor borehole.

6.3.4 The Cypress Hills Section

G:P Ratios

Both the G:P ratio for species ($G:P_{sp}$) and G:P ratio calculated on the basis of the affinity of individual dinocysts ($G:P_{ind}$) generally trend together (Figure 6.3A), with exceptions noted in sample 4321 (where $G:P_{sp}$ decreases while $G:P_{ind}$ increases), between samples 4278 and 4268 (where the plots are decoupled), and in samples 4228 and 4214 (where $G:P_{sp}$ increases while $G:P_{ind}$ decreases). In the majority of samples, $G:P_{sp}$ was found to be greater than or equal to $G:P_{ind}$. Overall, $G:P_{ind}$ changed more sharply than $G:P_{sp}$.

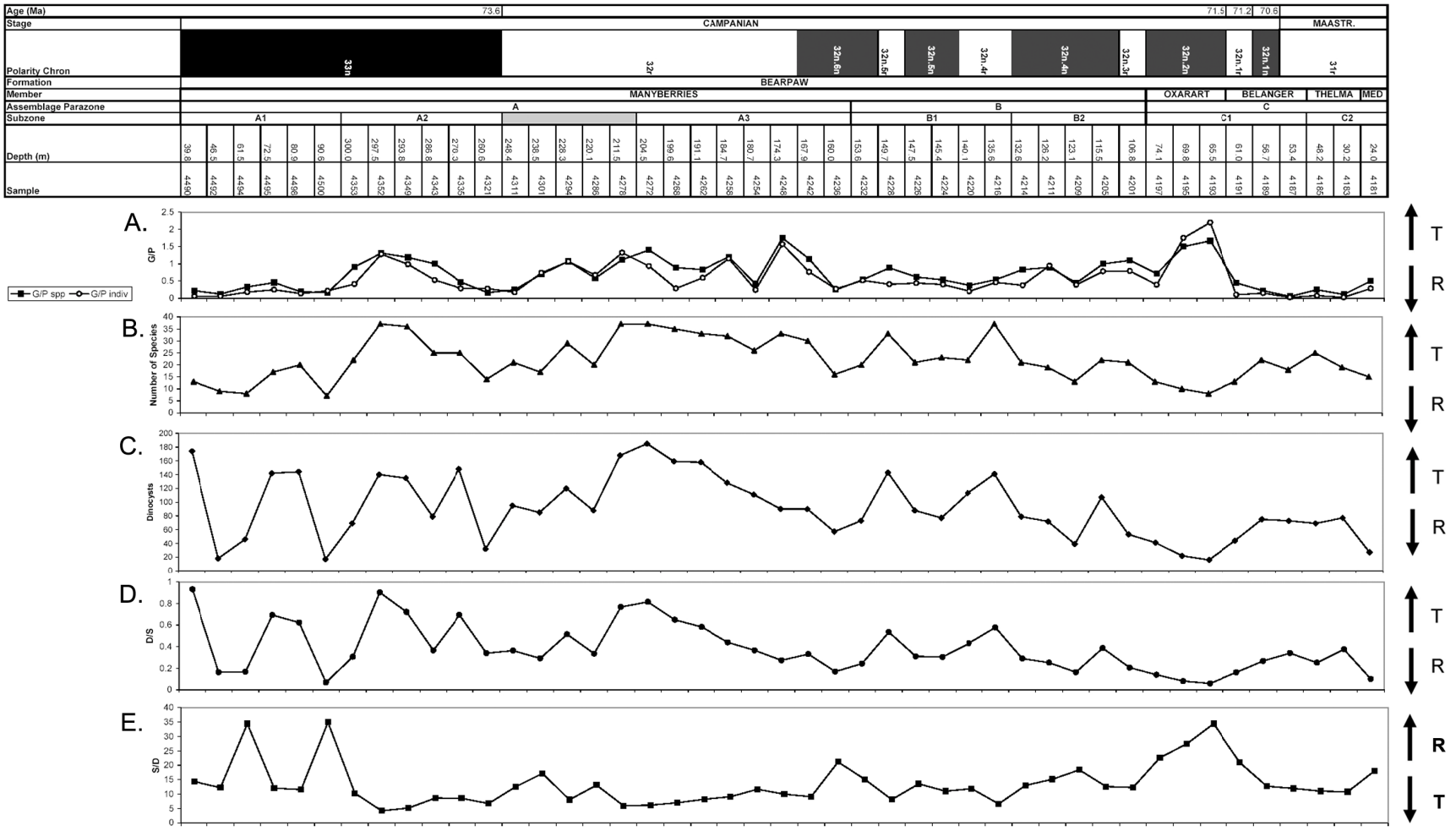
Both ratios increase in the lower third of the Manyberries Member in the lower half of chron 33n, indicating a diversification of the assemblage with an increased presence of gonyaulacacean taxa, before decreasing to a low during the 33n-32r

transition. Subsequent acmes, where the assemblage becomes more gonyaulacoid-dominant, are apparent in sample 4248 at the top of chron 32r – preceded by a sudden drop in sample 4254 – and in sample 4193 in the upper Oxarart Member in subchron 32n.2n. $G:P_{sp}$ is greater than $G:P_{ind}$ in the former incident, while the opposite is true in the latter case, with $G:P_{ind}$ greater than $G:P_{sp}$ by a value of approximately 0.5.

Succession Diversity & Dominance

The assemblage was found to be the most diverse, with the highest numbers of species and cysts recorded, in the Manyberries Member beginning with a steady rise in the number of species in the lower third of the member in chron 33n (Figure 6.3B). The number of species per sample first reaches its peak in the middle of chron 33n, gradually declining during the 33n – 32r transition, and again reaches a maximum peak in the lower half of chron 32r before a more gradual decline through the rest of 32r into subchron 32n.6n. Two additional, short-lived peaks occur in subchrons 32n.5r and 32n.4r, prior to a sharp decline during the transition into the Oxarart Member and a weak rebounding in the Belanger and Thelma members.

Figure 6.3: Results of semi-quantitative analyses of dinocyst taxa recovered from the composite Cypress Hills section, correlated with the magnetostratigraphy of Lerbekmo and Braman (2002). Biozonation described in section 6.5 of text. A. G:P ratios; B. Number of species per sample; C. Number of dinocysts per sample; D. D:S ratio; E. S:D ratio. Arrows indicate transgression (T) and regression (R). 'Maastr.' = Maastrichtian. 'Med.'= Medicine Lodge Member. Ages of magnetochrons from Ogg and Smith (2004).


Age (Ma)
73.6
71.5
71.2
70.6
Stage
CAMPANIAN
MAASTR.
Polarity Chron
33n
32r
32n.6n
32n.5r
32n.5n
32n.4r
32n.4n
32n.3r
32n.2n
32n.1r
32n.1n
31r
Formation
BEARPAW
Member
MANYBERRIES
OXARART
BELANGER
THELMA
MED
Assemblage Parazone
A
B
Subzone
A1
A2
A3
B1
B2
C1
C2
Depth (m)
39.8 46.5 61.5 72.5 80.9 90.6 300.0 297.5 293.8 286.8 278.3 260.6 248.4 238.5 228.3 220.1 211.5 204.5 199.6 191.1 184.7 180.7 174.3 167.9 160.0 153.6 149.7 147.5 145.4 140.1 135.6 132.6 126.2 123.1 115.5 106.8 74.1 69.8 65.5 61.0 56.7 53.4 48.2 30.2 24.0
Sample
4490 4492 4494 4495 4498 4500 4353 4352 4349 4343 4335 4321 4311 4301 4294 4286 4278 4272 4263 4262 4258 4254 4248 4242 4236 4232 4228 4225 4224 4220 4216 4214 4211 4209 4205 4201 4197 4195 4193 4191 4189 4187 4185 4183 4181
A.
G/P
G/P spp
G/P indiv
B.
Number of Species
C.
Dinocysts
D.
D/S
E.
S/D
T
R
T
R
T
R
T
R
R
T

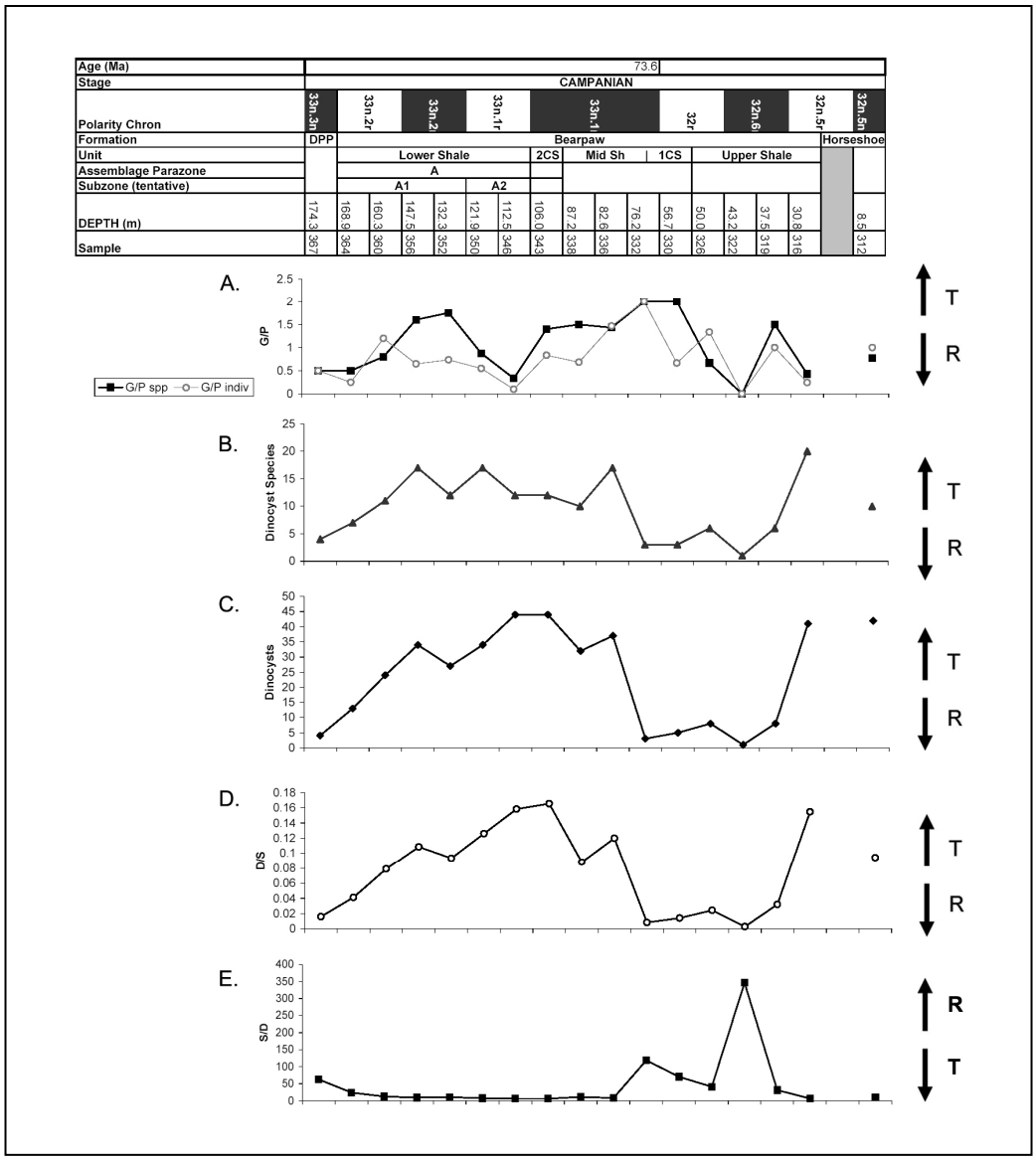


Figure 6.4: Results of semi-quantitative analyses of dinocyst taxa recovered from the RCA Castor core, correlated with the magnetostratigraphy of Lerbekmo et al. (2003). Biozonation described in section 6.5 of text.
A. G:P ratios; B. Number of species per sample; C. Number of dinocysts per sample; D. D:S ratio; E. S:D ratio. Arrows indicate transgression (T) and regression (R). DPP = Dinosaur Park Formation; 1CS = First Castor Sanstone; 2CS = Second Castor Sandstone. Ages of magnetochrons from Ogg and Smith (2004).

The number of dinocysts recovered per sample (Figure 6.3C) trends closely with the number of species per sample throughout most of the section, with the exception of the lower third of the Manyberries Member in chron 33n collected from outcrop near the Manyberries type locality. Here, the assemblage is dominated by a few peridinoid species, represented by a relatively large number of dinocysts, particularly in samples 4490 to 4495. This suggests that the initial transgression of the Bearpaw Sea into the area created a marginal, estuarine environment in which comparatively few taxa thrived in large numbers.

The assemblage recovered from sample 4490 is noticeably different in its composition from later samples, especially in the high abundance of a bicavate taxon of uncertain generic affinity (listed as 'Dinoflagellate sp. 1) as well as the cavate species *Chatangiella turbo, Chatangiella spectabilis* and *Senegalinium obscurum,* and the proximate species *Palaeoperidinium cretaceum, P. parvum, P. pyrophorum, Phelodinium tricuspe, Spinidinium clavus* and *Gonyaulacysta* cf. *eisenackii. Dinogymnium digitum* and *D. sibricum,* as well as the acritarchs *Fromea fragilis* and *Palambages morulosa,* round out the recovered flora. Chorate forms are completely absent.

The assemblage was observed to undergo an abrupt drop in the number of individual cysts and an accompanying increase in terrestrial influx in the subsequent sample (4492), with only a slight decrease in the number of species. Succeeding assemblages were then observed to recover and gradually grow in diversity, including the recovery of chorate cysts in samples 4494 and 4495 with an accompanying relative decrease in terrestrial influx. The flora declines abruptly from an acme in sample 4498 to an extreme low in sample 4500, accompanied by a spike in terrestrial influx.

The assemblages recovered from the Thelma well deposited after sample 4500 record a second increase in dinocysts and species per sample, reaching a new peak in sample 4353 with a complementary decrease in terrestrial influx. This is followed by a decline with its low point in sample 4321, before reaching a maximum in sample 4272 in the middle of the member. Thus, the assemblages recovered from the surface section likely record the initial incursion of the Bearpaw Sea into the area that took the form of an initial transgressive pulse, followed by an off-lap of the sea prior to a more persistent inundation.

Terrestrial Influx (D:S and S:D ratios)

The D:S ratio (Figure 6.3D) was found to trend extremely well with the numbers of dinocysts per sample, particularly through chron 33n in the lower Manyberries Member, and also trends closely with the number of species recovered. Correlation between the three trends is especially obvious through the upper two-thirds of the Manyberries Member (chron 32r through subchron 32n.3n) and in the Oxarart and lower Belanger members (subchrons 32n.2n through 32n.1r). As would be expected, the S:D ratio (Figure 6.3E) follows an inverse trend that is particularly noticeable as peaks in the basal portion of the Manyberries Member and in the Oxarart Member, possibly demarcating the position of the latter member's sandstone unit.

6.3.5 The RCA Castor Section

G:P Ratios

The $G:P_{sp}$ and $G:P_{ind}$ ratios are not as closely coupled in the Castor succession as in the Cypress Hills material (Figure 6.4A). Particularly, both trends are decoupled throughout the lower half of the section with a lag apparent in $G:P_{ind}$ when compared with $G:P_{sp}$ in chron 32r. This discrepancy may be due to the recovery of a relatively large number of species, each only represented by a few individual cysts.

$G:P_{sp}$ rises throughout much of the lower shale unit in subchrons 33n.3n through 33n.2n, coinciding with the increase in diversity evidenced by the number of species and dinocysts recovered per sample. It then undergoes a decrease in chron 33n.1r, coinciding with a decrease in species but continued increase in dinocysts per sample. This suggests that peridinialean species are dominant during this interval, with a subsequent episode of diversification to a flora dominated by gonyaulacacean taxa. $G:P_{ind}$ appears to respond more closely to the trends observed in the lithostratigraphy, showing a reduction (indicating a high proportion of peridinoid cysts) during the 2CS and 1CS intervals, whereas $G:P_{sp}$ shows a positive trend throughout the 2CS and middle shale interval, reaching a maximum that correlates with the 1CS. However, poor recovery of dinocysts through the 1CS interval in chron 32r and subchron 32n.6n undoubtedly skew the ratios and make any conclusions that could be drawn from the trends observed in chron 32r and the base of subchron 32n.6n highly suspect. The decrease in both G:P ratios in subchron 32n.5r occurs simultaneously with the positive excursions in the recovery of species and individual cysts, indicating a proliferation of peridinialean taxa during the transition to the marine interval at the base of the Horseshoe Canyon Formation.

Diversity and Dominance

As indicated in Figure 6.4 B and C, both the number of species and number of dinocysts per sample trend well together, with the exception of a lag observed midsection in the uppermost part of subchrons 33n.1r (sample 346) and 33n.1n (samples 343 through 336). A steady increase in both number of species and individual dinocysts is observed from the basal contact with the Dinosaur Park Formation (DPP) through the bottom half of the lower shale unit in the Bearpaw strata (subchron 33n.3n through the lower part of subchron 33n.2n). A slight decrease in both counts in sample 352 (subchron 33n.2n) is followed by a positive trend in both plots, followed by a decoupling: the number of species decrease in the vicinity of the Second Castor Sandstone (2CS) while the number of individual cysts remains relatively high. This suggests that a shift in habitat conditions occurred during the deposition of the 2CS, creating a more marginal environment in which a smaller number of eurytopic species thrived.

Both trends synchronize immediately above the 2CS in subchron 33n.1n, rising in the middle shale unit before decreasing through the First Castor Sandstone (1CS) interval in chron 32r. The lowest recovery of an already sparse assemblage occurs in the lowest part of the upper shale unit above the 1CS interval, at the base of subchron 32n.6n. A positive trend is then observed through the remainder of the upper shale unit, reaching an acme prior to the transition into the Horseshoe Canyon Formation.

Terrestrial Influx (D:S and S:D ratios)

The semi-quantitative assessment of terrestrial influx as measured by the D:S ratio (Figure 6.4D) shows a trend that is nearly identical to that of the dinocysts recovered per

sample. A positive trend is apparent throughout the lower shale unit, followed by a negative excursion through the 2CS interval (indicating conditions high in terrestrial influx). An even more drastic decline in both trends is evident through the 1CS interval. The S:D ratio (Figure 6.4E) is comparatively flat throughout most of the lower part of the section, due in large part to poor resolution because of the comparatively high number of terrestrial palynomorphs encountered. A positive trend is apparent in the middle shale unit that paradoxically declines through the deposition of the 1CS. A strongly positive excursion in sample 322 correlates with the drastic decreases in the D:S ratio and the recovery of dinocysts.

6.4 BIOSEQUENTIAL INTERPRETATION

6.4.1 Cypress Hills Section

The increases in the G:P ratios and number of species recovered from strata encompassed by chron 33n suggest that the initial incursion of the Bearpaw Sea into the Cypress Hills was composed of two transgressive pulses: a small event recorded in the assemblages recovered from the Manyberries outcrop preceding the main flooding episode in the upper half of chron 33n in the RCA Thelma borehole. In the first flooding event a high amount of terrestrial influx as recorded by the S:D plot likely influenced the strongly peridinoid-dominant dinocyst flora, possibly through a decrease in salinity, increase in turbidity or other habitat conditions that made the marginal environment suitable for tolerant peridinoid taxa. During the second inundation, the dinocyst flora diversified from being dominated by peridinialean taxa to one where gonyaulacacean taxa were present in equal to near-equal numbers. The acme within this positive episode in the

middle of chron 33n (sample 4352) is correlated with a low point in terrestrial influx as recorded by the S:D plot.

The decline in G:P ratio, recovered species and individual dinocysts in the 33n-32r transition is accompanied by a slight increase in terrestrial influx. This may indicate a distal retrenchment of the Bearpaw Sea, leading to estuarine conditions and increased continental run off delivering more terrestrial palynomorphs and freshwater into the area. Similar declines in the assemblage with an increase in terrestrial influx occurs to a lesser extent in sample 4286 and to a greater extent in samples in the upper part of chron 32r, lower part of subchron 32n.6n and subchron 32n.4n in the Manyberries Member and in the base of the Oxarart Member in subchron 32n.2n.

The basal 32r regression gives way to a period of increased diversity in numbers of species and dinocysts, decreased terrestrial influx and a gonyaulacacean-dominated flora, reaching a peak in diversity and G:P ratios in the middle of chron 32r, suggesting a period of highstand conditions to the end of the chron, followed by a series of gradual regressive pulses and moderately increasing amounts of terrestrial influx that can be seen as troughs in subchrons 32n.6n, 32n.5n and 32n.4n in the Manyberries Member. These regressive conditions persist throughout the rest of the section, with conditions more suited to flora dominated by peridinialean taxa through the Oxarart, Belanger, Thelma amd Medicine Lodge members in subchron 32n.2n through chron 31r. The assemblages recovered from the Belanger, Thelma and Medicine Lodge members (subchron 32n.1r through chron 31r) are more diverse than those found in the terminal Oxarart Member with flora dominated by peridinialean taxa in habitats experiencing a moderate amount of terrestrial influx.

The peak in both G:P ratios in the upper Oxarart Member in subchron 33n.2n differs dramatically from the previous peaks in showing an inverse relationship between the numbers of species and dinocysts recovered and a strong correspondence with the peak in terrestrial influx. The assemblages recovered from the interval (samples 4193 and 4195) were found to be poorly preserved with a very high phytoclast content. Considering the small number of dinocysts recovered and their poor state of preservation, the actual prevalence of gonyaulacacean taxa in this interval is somewhat uncertain, particularly when the inverse relationship between the numbers of species and cysts recovered and the terrestrial influx is consistent with other observations from the rest of the section and the Castor well.

6.4.2 Castor section

The location of the Castor well to the north and west of the Cypress Hills at the landward margin of the central Alberta embayment of the Bearpaw Sea restricted the deposition of the Bearpaw Formation in the area to chrons 33n, 32r, and subchrons 32n.6n and 32n.5r, equivalent to the lower two thirds of the Manyberries Member in the Cypress Hills. This resulted in a much more marginal environment susceptible to a much higher degree of terrestrial influx, as well as regressive pulses of the seaway. This is evident lithologically in the deposition of the 1CS and 2CS. However, the small sample sizes of many of the recovered assemblages limit their reliability as a sequence stratigraphic signal.

The dinocyst succession within the Castor well records a fairly rapid flooding that inundated the underlying Dinosaur Park Formation from subchron 33n.3n through 33n.2n, indicated by increases in G:P_{sp} and the number of species and cysts per sample

(Figure 6.4). This transgression results in a diverse, gonyaulacacean-dominated flora in the middle of the lower shale unit in the upper part of subchron 33n.2n. This flooding episode and transgressive peak likely correlates with the second peak recorded in chron 33n in the Cypress Hills section.

The D:S ratio and number of dinocysts recovered remains high through the start of deposition of the 2CS but does show a decline through the interval into the middle shale unit. A slight rise is noted in the upper part of subchron 33n.1n (sample 336) prior to a sharp decline in diversity and D:S ratio, with a corresponding positive excursion in the S:D ratio, coinciding with the deposition of the 1CS at the transition in chron 32r. The deposition of the 1CS is likely the result of the same regressive event recorded in the 31n-32r retrenchment in the Cypress Hills, but is more extreme here owing to the Castor well's more proximal location.

Conditions remain closed and marginal in the upper shale unit throughout subchron 32n.6n, although peridinoid taxa make a strong resurgence in chron 32n.5r, as indicated by the positive excursion in species and dinocysts per sample and decrease in G:P ratio. A similar upswing is present in the same subchron in the Cypress Hills section, indicating a transgressive episode.

6.5 BIOZONATION

Harland (1973) first posited an informal biozonation for his succession from the Bearpaw Formation near Lethbridge, based on the percentage of dinocysts in a sample (= D:S ratio in this study, multiplied by 100), the number of dinocyst species per sample and the ratio of gonyaulacacean to peridinialean species ($G:P_{sp}$ in this study), as well as the observed ranges of some taxa. As part of his study, Harland attempted to extend his

zonation scheme east into the Cypress Hills using assemblages recovered from the RCA Thelma core. He reported that he could only discern his Assemblage Zone II based only on semi-quantitative measures and not on the ranges of the dinocysts.

6.5.1 Biozonation of the Cypress Hills section

A similar procedure was attempted, using the same semi-quantitative measures as well as the first and last occurrences of dinocysts within the Cypress Hills section. Common events within the semi-quantitative trends such as shared peaks and troughs were first assessed and then correlated against biostratigraphic events within the Cypress Hills succession. Three major assemblage parazones, labelled in ascending order as A, B and C were first erected on the basis of notable changes within the semi-quantitative trends and changes in the dinocyst succession either as several FO or an extirpation surface, defined as the LO of four or more taxa. Subzones were established based primarily on semi-quantitative events and the LO of four or fewer taxa. Parazones and subzones in the Cypress Hills section are included on Figure 6.3.

PARAZONE A: This assemblage zone encompasses the lower two-thirds of the Manyberries Member, from the base of chron 33n to the middle part of subchron 32n.6n. It was erected primarily on the basis of semi-quantitative trends, specifically the decline noted in both G:P ratios, species per sample, dinocysts per sample, D:S ratio and positive excursion in the S:D ratio. It includes three subzones:

- Subzone A1: This subzone ranges through the lower half of chron 33n and consists of all of the assemblage recovered from the outcrop near Manyberries, Alberta from the basal contact of the Bearpaw Formation with the underlying Lethbridge Coal Zone in the Dinosaur Park Formation. It is semi-quantitatively

defined by the negative excursion observed in the G:P ratios, species per sample, dinocysts per sample, D:S ratio and second peak in the S:D ratio. The top of the subzone is defined palynologically by the LO of Dinoflagellate sp. 1 and *Chatangiella turbo*.

- Subzone A2: Consists of the remainder of chron 33n, from the negative excursion that demarcates it from subzone A1 to the next negative excursion observed in all the trends, including the S:D ratio. Its base is noted by the FO of several gonyaulacacean taxa, particularly *Spiniferites pseudofurcatus, Hystrichosphaerdium tubiferum, Oligosphaeridium complex, O. pulcherrimum, Criboperidinium exilicristatum* and *Dapsilidinium marinum.* The gonyaulaceans *Downiesphaeridium armatum, Spiniferites ramosus, Oligosphaeridium anthophorum, Circulodinium distinctum,* and *Tanyosphaeridium variecalmum* have FO's within the subzone. The peridinoid *Cerodinium* cf. *diebellii* als has its FO at the subzone's base, and the acritarch *Fromea fragilis* also increases noticeably in abundance. This subzone is considered to be equivalent to "informal assemblage Zone I" of Harland (1973).
- Subzone A3: Spans the upper half of chron 32r through the midpoint of subchron 32n.6n. Its presence is observed as a gradual negative trend in the G:P ratios, species per sample, dinocysts per sample and D:S ratio and positive excursion in S:D ratio. It is defined biostratigraphically with the LO of *Dinogymnium longicorne* at its base and the LO of *Pervosphaeridium truncatum* at its top. *Downiesphaerdium? aciculare, Prolixosphaerdium parvaspinum, Cometodinium* cf. *whitei, Cerodinium speciosum* all have LO's within this subzone. The position

of these occurrence data when combined with the perceived semi-quantitative trends result in subzone A3 not being contiguous with subzone A2. This subzone is considered to contain Harland's Assemblage Zone II, based on its measured position in the stratigraphic column and correlation with his semi-quantitative measurements.

PARAZONE B: Encompasses the upper third of the Manyberries Member, from the upper part of subchron 32n.6n to the upper contact of subchron 32n.3r. This parazone and its two subzones are established primarily on biostratigraphic evidence, including two extirpation surfaces.

- Subzone B1: This subzone extends from the contact with parazone A in the upper half of subchron 32n.6n to the top of subchron 32n.4r. Its top is defined biostratigraphically on the LOs of *Odontochitina operculata, Phelodinium magnificum, Eucladinium spinossinum* and *Florentinia mantellii* in a single extirpation surface, preceded by the LO's of *Dinogymnium sibiricum* and *Exochosphaeridium phragmites*. It is also noted by the FO's of *Alterbidinium acutulum* and *Chatangiella granulifera* within the subzone. Semi-quantitatively, the subzone includes two peaks observed in the counts of species and dinocysts per sample, and the D:S ratio. Its terminus is defined by the decrease from the second peak in these three measurements. It is considered to encompass Harland's assemblage zone III.
- Subzone B2: The top of this subzone is defined primarily by an extirpation surface consisting of the LOs of *Dinogymnium acuminatum,*

Spongodinium delitiense, Downiesphaeridium sp. A.*, Oligosphaeridium pulcherrimum* and *Dapsilidinium marinum*. Semi-quantitatively, the subzone is defined by a slightly negative trend that includes a trough and peak in the middle of the section in the plots of species and dinocysts per sample and D:S ratio and a flattening of the G:P ratios.

PARAZONE C: This parazone encompasses the Oxarart, Belanger, Thelma and Medicine Lodge members, from the base of subchron 33n.2n to the top of the recovered section in chron 31r and includes the Campanian-Maastrichtian boundary interval within the section. It consists of two subzones.

- Subzone C1: This subzone encompasses the Oxarart and Belanger members from subchron 33n.2n through the lower part of chron 31r. Semi-quantitatively it is characterized by a shallow depression, followed by a positive excursion in numbers of species and dinocysts recovered and a spike in S:D ratio. The large positive excursion in the G:P ratios is considered to be skewed by poor specimen recovery in samples 4195 and 4193. The top of the subzone is characterized biostratigraphically by an extirpation surface consisting of the LOs of *Chatangiella tripartita, Isabelidinium microarmum, Spinidinium echinoidea* and *Alterbidinium* cf. *montanense.* This surface is preceded by the LOs of *Hystrichosphaeridium arborispinum* and *Achomosphaera ramulifera*. The subzone is also noted for the FO of *Alterbidinium minor,* which along with *A. acutulum* becomes increasingly prevalent in the succession. This increase in abundance at the top of the subzone coincides with the 32n-31r polarity transition

- Subzone C2: The base of the subzone coincides with the base of the Thelma Member in the section, encompassed by chron 31r. It is defined semi-quantitatively by a slight increase in G:P ratios and gradual decreases in the numbers of species and dinocysts recovered and D:S ratio. Two extirpation surfaces are apparent, the first at the subzone's base consisting of the LO's of *Chatangiella biapertua, C. ditissima, C. spectabilis, Trithyrodinium suspectum, Criboperidinium excilicristatum, Spiniferites pseudofurcatus* and *Hystrichosphaeridium tubiferum* (including var. *brevispinum*). The second surface occurs within the subzone and consists of the LO's of *Alterbidinium dictyotum, Chatangiella decorosa, Isabelidinium acuminatum, Senegalinium obscurum, Palaeoperidinium parvum, Spinidinium clavus, Phelodinium tricuspe* and *Laciniadinium biconiculum.*

6.5.2 Biozonation of the Castor section

It is not considered possible to reliably extend this zonation scheme into the Castor well based on biostratigraphy as the assemblage composition is too closely tied to local environmental conditions. However, on the basis of the semi-quantitative trends and magnetostratigraphy it is proposed that most of the Castor section falls within parazone A, with subzone A1 apparent from subchron 33n.3n through 33n.2n and with subzone A2 present from subchron 33n.1r until the deposition of the Second Castor Sandstone (Figure 6.4).

7.0 PALAEOECOLOGICAL INTERPRETATION AND SYNTHESIS

7.1 UTILITY OF DINOFLAGELLATES IN PALAEOECOLOGICAL INTERPRETATION

As an important constituent of the phytoplankton, dinoflagellates are subject to a variety of environmental conditions including sea surface conditions such as temperature (de Vernal et al., 1993, 1998; Veerstegh, 1994; Brinkhuis et al., 1998; Rochon et al., 1998, 1999), salinity (Wall et al., 1973; Wall and Dale, 1974; Pross and Schmiedl 2002), oxygenation (Pross, 2001) and the availability of nutrients (i.e. Williams, 1971 a and b; Dale, 1976; Dale, 1996; among others) that are reflected in the composition of the cyst assemblage deposited in sediments. In Recent sediments, this is often used to assess the extent of the impact of anthropogenic activity which leads to enhanced eutrophication and economically damaging dinoflagellate blooms (Wang et al., 2004; Pospelova et al., 2005). In ancient sediments, the thanatocoenoses of dinocyst assemblages preserve palaeoenvironmental signals that can be used to elucidate depositional environments and proximal-distal trends in sea-level change (Sluijs et al., 2005).

Davies et al. (1982) grouped the various analytical approaches used to link palynomorph assemblages to palaeoenvironmental studies into four categories: (1) the absolute abundance of dinocysts per unit of sediment or water; (2) the relative abundance of dinocysts versus other palynomorphs within an assemblage; (3) diversity and dominance of taxa within an assemblage; and (4) the assemblage composition, including the relative abundance of a given taxa or morphotype within the assemblage. The first approach, absolute abundance of dinocysts, was not performed in this study and is usually confined to studies of Recent assemblages. For the purposes of this discussion, comments will be confined to the latter three categories with regards to this study.

7.1.1 Relative abundance of dinocysts to other palynomorphs

In this study, the D:S and S:D ratios were used as proxies for terrestrial influx within the recovered assemblages. Harker (1977) also used D:S ratio along with diversity and equitability indices to deduce the extent of terrestrial influence on recovered assemblages. It was found that a greater D:S ratio positively correlated with increasing diversity and equitability within the assemblage, which was interpreted as greater distance away from sources of terrestrial influx. A similar approach was used by Harland (1973) who used the percentage of phytoplankton as one of his semi-quantitative measures. Ioannides (1986) used relative proportions of microplankton, sporomorphs and fungal spores to assess facies changes within his sections.

As discussed in the previous chapter, the D:S ratio was found to trend closely with the count of individual dinocysts per sample, and to a lesser extent with the number of species per sample. This is especially noticeable within the Castor section, where the D:S ratio is practically identical to the number of individual cysts per sample, with the exception of the uppermost sample in the column. The difference in the overall degree of terrestrial influx between the two sections is also immediately apparent when one considers that the values of the S:D ratio in the Castor well are an order of magnitude greater, and the values of D:S ratio an order of magnitude smaller, than the respective values from the Cypress Hills. This supports the conclusion that the Castor section was deposited under more marginal, proximal conditions than the Cypress Hills.

7.1.2 Diversity and Dominance

It has been demonstrated by several workers that species diversity within a cyst assemblage is an extremely useful parameter in ecological interpretation of both modern

and ancient depositional environments. Generally, species diversity tends to increase in the offshore direction, and coastal and estuarine assemblages tend to consist of fewer species, often with a single species being predominant (Wall et al., 1977). This is potentially due to more unstable environments caused by fluctuations in temperature and salinity that can be withstood by only a few taxa (Williams and Sarjeant, 1967; Wall et al., 1977; Goodman, 1987; McMinn, 1991). The most diverse assemblages tend to be those occupying waters overlying a continental shelf.

The diversity and dominance of taxa within the recovered sections were evaluated qualitatively in this study, through the comparison of G:P ratios and numbers of species and specimens per sample with relative abundance of taxa within the assemblage. In both the Cypress Hills and Castor sections, the most diverse assemblages correlated with a high G:P_{sp} ratio and large number of species per sample. This situation was observed in the lower part of both sections, interpreted as peak transgression of the Bearpaw Sea. Conversely, in the upper part of both sections, low G:P ratios and elevated numbers of species and individual cysts per sample denote low diversity assemblages, dominated by a few peridinoid taxa, suggesting marginalized conditions more suited to a eurytopic assemblage.

7.1.3 Assemblage Composition

The relative abundances of particular taxa or morphotypes within the assemblage are most commonly used to assess palaeoenvironmental conditions. This can take the form of a ratio between morphotypes, such as the G:P ratio or ratio between taxa with known environmental affinities, such as between specimens of the offshore genus

Spiniferites and more nearshore *Cyclonephelium* (Habib and Miller, 1989; Habib et al., 1992; Li and Habib, 1996;).

Another approach, first used by Downie et al. (1971), uses associations between taxa and depositional conditions. They recognized four associations in dinocyst assemblages from the early Eocene of southeast England: the *"Hystrichosphaera"* Association, dominated by specimens of the chorate genera *Spiniferites, Achomosphaera, Cordosphaeridium* and *Hystrichosphaeridium* denoting open marine conditions; a *Micrhystridium* Association, consisting of the acritarch genera *Micrhystridium* and *Comasphaeridium*, indicating an inner neritic environment; a *Wetzeliella-Deflandrea* Association, indicating lagoonal to brackish environments; and an *Aeroligera* Association, also marking an offshore marine environment.

In their pioneering study of 108 dinocyst assemblages along nearshore to offshore transects, Wall et al. (1977) identified eight associations of dinocysts, broadly categorized as estuarine, estuarine-neritic, neritic and oceanic groups composed of taxa specific to those locations along the transects. For example, the genus *Impagidinium* was found to be limited consistently to the most distal oceanic settings, while species of *Nematosphaeropsis* were indicative of a more neritic environment (Sluijs et al., 2005, p. 298).

A similar approach was used by Brinkhuis (1994) in interpreting the palaeoecology of dinocyst assemblages along a proximal-distal transect from the late Eocene to Early Oligocene transition in northeast Italy. His analysis resulted in a schematic transect based on optimum abundances along an inner neritic to oceanic

transect, illustrated in Figure 7.1. Along the transect, the genera *Spiniferites* and *Cleistosphaeridium* are considered to be diagnostic of an outer neritic, shelf environment.

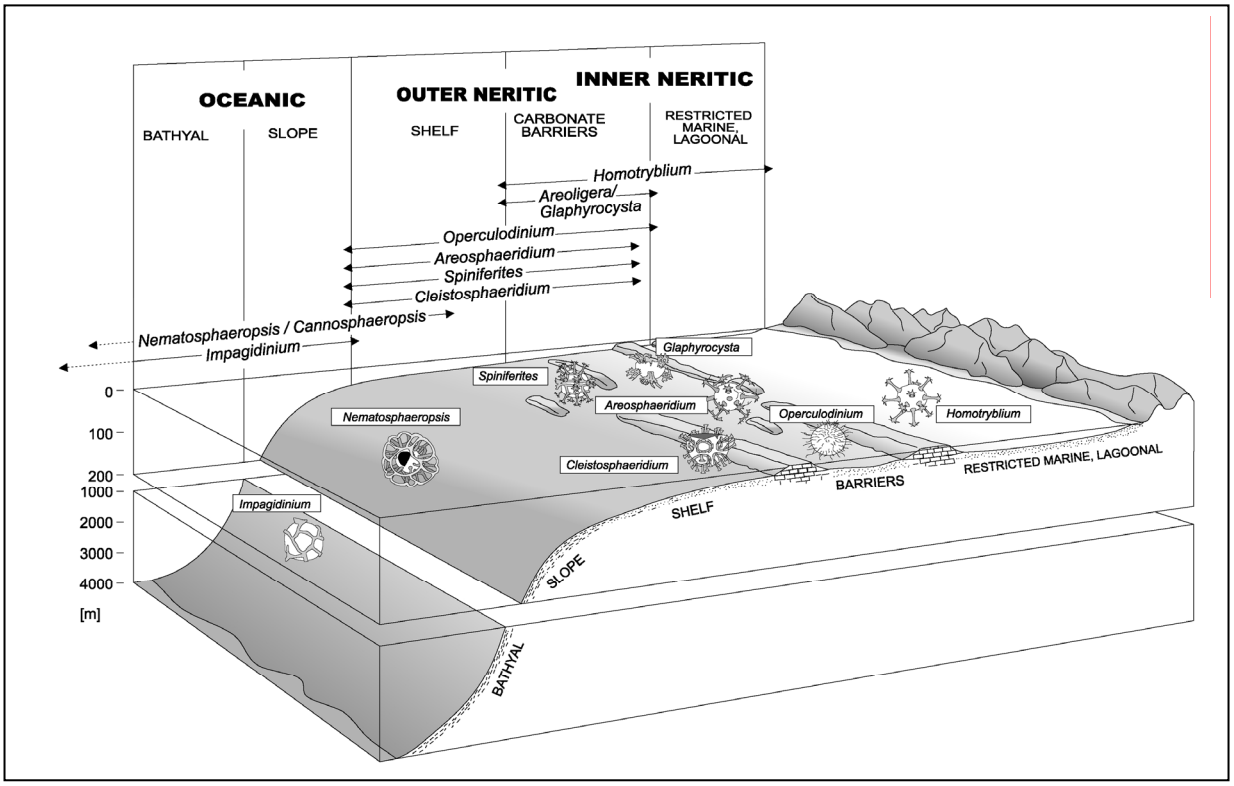


Figure 7.1: Schematic model of Brinkhuis (1994) for dinocyst distribution along a proximal-distal transect during the Late Eocene-Early Oligocene of central Italy (from Sluijs et al., 2005). Dinocyst associations within the recovered assemblages from this study range from inner neritic (restricted conditions) to outer neritic shelf conditions.

In this study, interpretation based on assemblage composition relied primarily on $G:P_{sp}$ ratio, the results of which are discussed in detail for each section in the previous chapter. Although construction of a detailed transect of dominant taxa was not conducted, it is possible to draw some comparisons with the above environmental associations. Peaks in the $G:P_{sp}$ ratio correspond to the prevalence of the genera *Spiniferites, Achomosphaera, Downiesphaeridium, Hystrichosphaeridium* and *Circulodinium* in subzones A2, A3 and B2 in the Cypress Hills section (Figure 7.2) and to *Spiniferites, Achomosphaera, Downiesphaeridium* and *Oligosphaeridium* in the Lower Shale and Upper Shale transition in the Castor Section (Figure 7.3), suggesting that these intervals were the most openly marine within their respective sections, perhaps becoming as distal as an outer neritic-shelf environment in the Cypress Hills section.

7.2 CORRELATION WITH OTHER PALAEOENVIRONMENTAL INDICATORS

7.2.1 Palaeotemperature

Several studies over the last 40 years have attempted to elucidate palaeoenvironmental conditions in the Western Interior Seaway through geochemical studies of fossils and rocks from the basin. He et al. (2005) reported the $\delta^{18}O$ compositions of inoceramid bivalves and baculitid ammonoids spanning the entire Bearpaw cyclothem and based on these calculated palaeotemperature values for the interval. They found that the lowest isotopic values occurred during the *Baculites compressus, B. cuneatus* and *B. reesidei* zones which span the peak transgressive interval of the cyclothem (Caldwell, 1968; Gill and Cobban, 1973; Cobban et al., 1993), comparable to the period of deposition of the lower half of the Manyberries Member in the Cypress Hills section and the lower shale unit within the Castor section.

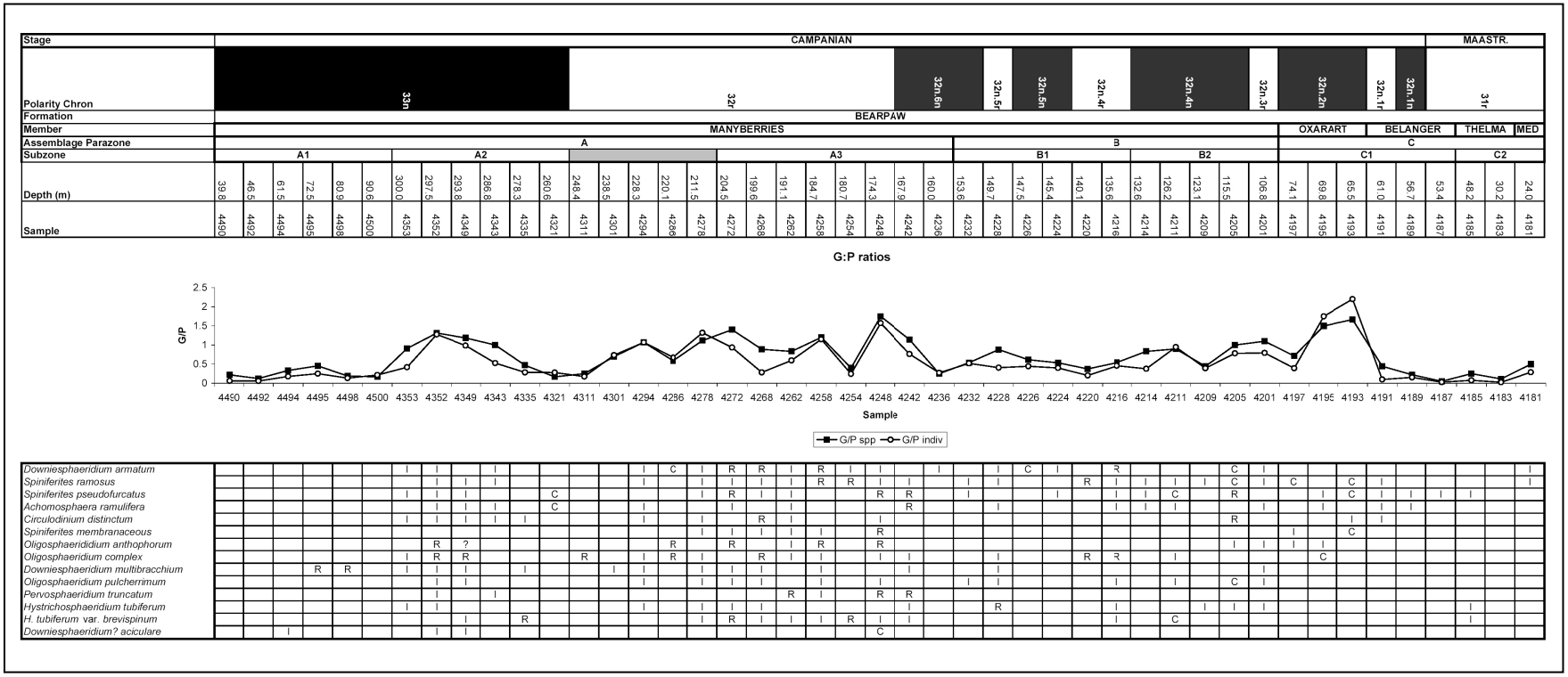


Figure 7.2: Association of taxa potentially indicative of open marine conditions compared with G:P ratios and magnetostratigraphy for the Cypress Hills section.

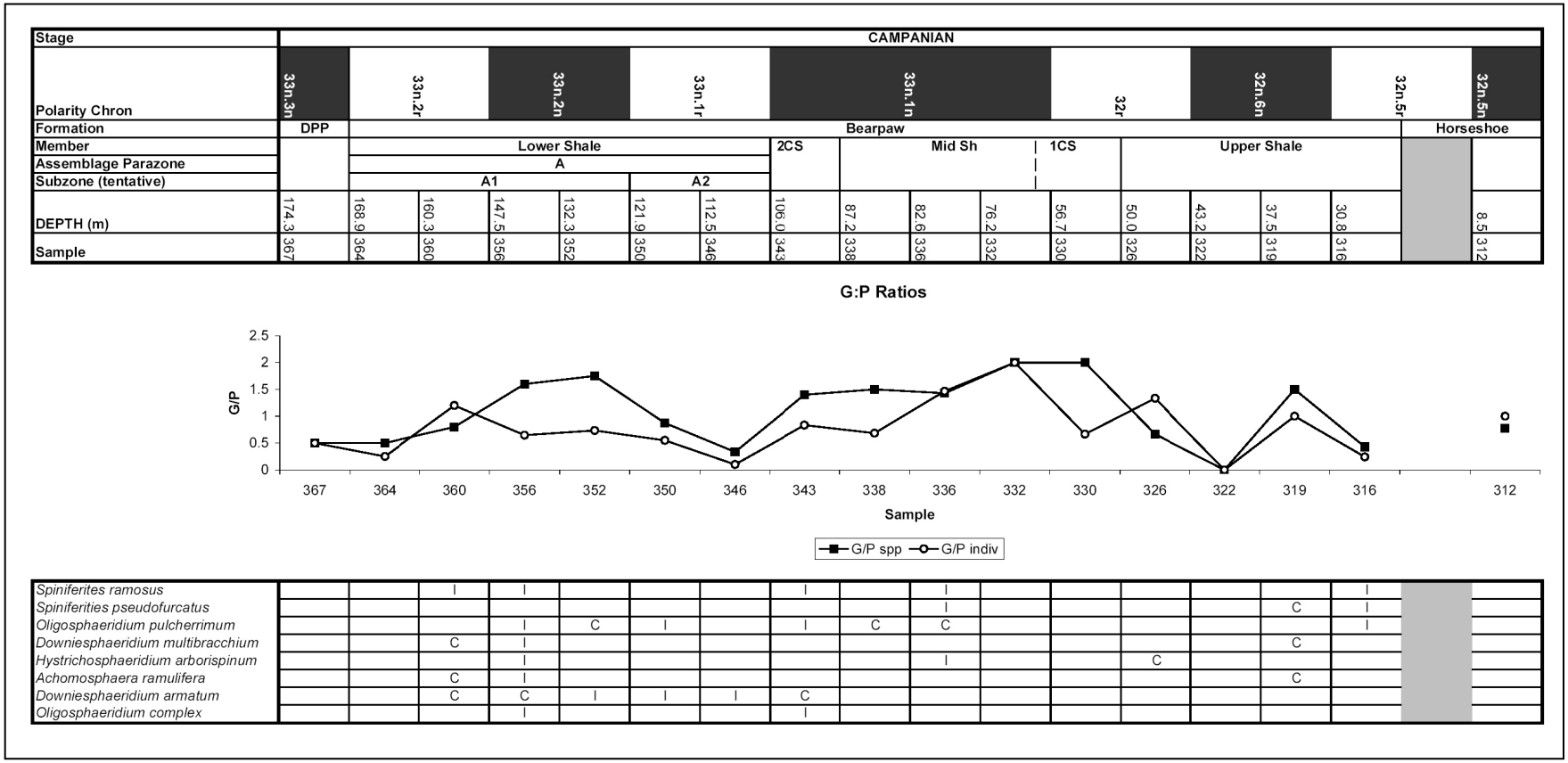


Figure 7.3: Association of taxa potentially indicative of open marine conditions compared with G:P ratios and magnetobiostratigraphy for the Castor section. CS = Castor Sandstone, Mid Sh = Middle Shale Unit, DPP = Dinosaur Park Formation

The depressed isotopic values were interpreted as elevated temperatures within the seaway as compared to the global ocean, rather than as the onset of brackish conditions as posited by previous workers. A rise in average temperature during the peak transgression was also put forward by Kauffman (1984) and Kauffman and Caldwell (1993), who argued that temperatures could rise as much as 5°C due to CO_2 degassing as the result of increased tectonism and volcanic activity at this time.

Using $\delta^{18}O$ values of the baculitids and ammonoids from the Bearpaw Sea, He et al. (2005) calculated an average temperature between 13°C and 17°C at the start of the Bearpaw transgression, rising to an average temperature of 20°C during peak transgression and decreasing to 14°C with the onset of regression. This suggests that the largest and most diverse dinocyst assemblages recovered from the Manyberries Member coincided with the warmest conditions (Figure 7.4). These warmer waters may also account for the reduced size range of some of the presumably boreal peridinialean taxa, such as species of *Chatangiella*, which were originally reported from presumably cooler environments from the Canadian Arctic and Siberia. This lower size range was also noted by Harker et al. (1990).

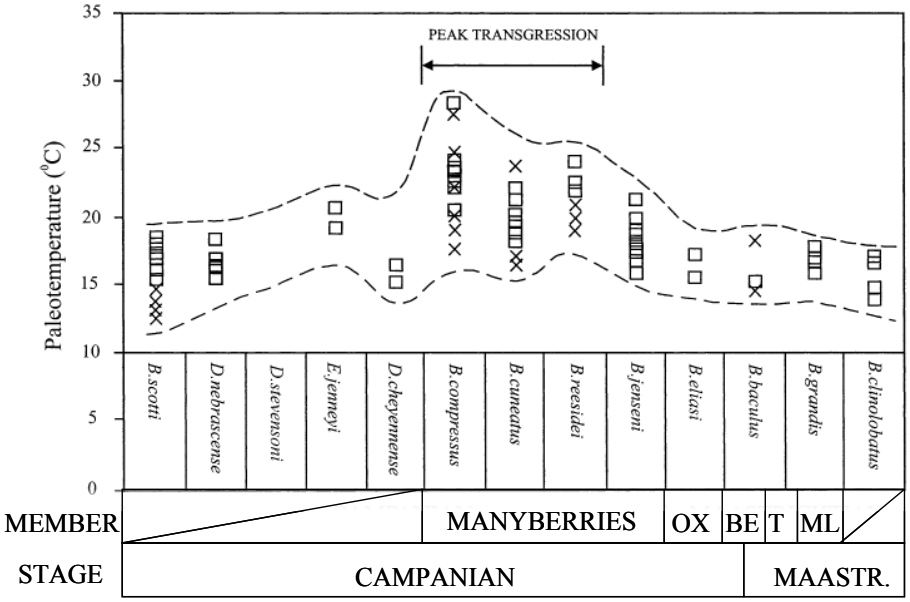


Figure 7.4: Correlation of the Cypress Hills section of the Bearpaw Formation with the $\delta^{18}O$ paleotemperature curve of He et al. (2005), obtained from stable isotope analysis of baculutid shells. "□" and "x" refer to samples from the United States and Canada, respectively. Abbreviations: "OX" = Oxarart Member. "BE" = Belanger Member, "T" = Thelma Member, "ML"= Medicine Lodge Member. Peak transgression of the Bearpaw Sea occurred between *B. compressus* and the end of *B. reesidei* Time (Caldwell, 1968; Gill and Cobban, 1973; Cobban et al., 1993). Adapted from He et al. (2005).

7.2.2 Facies Associations

Tsujita (1995a) and Tsujita and Westermann (1998) proposed four facies associations within the Bearpaw cyclothem, based on sedimentology and macropalaeontology of ammonoids from eight outcrop sections in south-central Alberta, including the Cypress Hills and Battle River near Castor. These included:

- Facies Association 1 (FA1): Open, offshore conditions – consisting of bioturbated mudstones and dark grey claystones and a diverse assemblage of fossil bivalves, lobsters and ammonoids such as species of *Placenticeras* and *Baculites*, including

juvenile and mature individuals. (Tsujita and Westermann, 1998, p. 141). Stratigraphic units interpreted as FA1 include the Manyberries Member (Tsujita, 1995a, figure B2);

- FA2: Storm-dominated, shallow offshore conditions – comprised of silty mudstones and "hummocky cross-stratified sandstones" indicative of more proximal marine conditions. The macrofossil assemblage was found to be not as diverse as in FA1, with ammonoids being less common. The cross-stratified sandstone was interpreted as evidence of sea-level fall below storm wave base. Plant material was also identified. FA2 was found to be prevalent in the upper portion of the Bearpaw Formation and was interpreted as evidence of a shift from offshore marine conditions to a more marginal inshore situation. (*ibid.*, p. 143). Units of this facies association include the mudstone intervals within the Oxarart, Belanger, Thelma and Medicine Lodge members in the Cypress Hills section and the shale units of the Castor core (Tsujita and Westermann, 1998, figure 2a and b);
- FA3: Wave-dominated nearshore to onshore sediments – consisting of clean sandstone units and ichnofossils indicative of near shore, wave-dominated conditions. The sandstones were interpreted as instances of forced regression, coupled with a rapid advance of wave-dominated beach conditions. Instances of FA3 included the sandstone units capping the Oxarart, Belanger and Thelma members (*ibid.,* p. 143); and
- FA4: Distal portion of prograding, fluvial-dominated delta – composed of interbedded brownish-grey mudstones and sandstones forming distinctive upward

coarsening packages, interpreted as representing prodeltaic deposits of a prograding delta. This facies was reported as recording the advance of delta environments of the lower Horseshoe Canyon Formation and creating a tide-dominated estuarine to brackish swamp environment (Tsujita and Westermann, 1998, p. 144; Ainsworth, 1994). The First and Second Castor Sandstones are interpreted as belonging to this association.

The palaeoecological interpretation of the assemblages recovered in this study corroborates facies associations of Tsujita and Westermann (1998). The interpretation of open, offshore marine conditions within the Manyberries Member corresponds with the recovery of a relatively diverse microplankton flora as evidenced by the positive trends and maximums in the semi-quantitative data (high G:P ratios and numbers of species and individuals per sample). The decline in semi-quantitative value and less diversity within the assemblages from the Oxarart, Belanger, Thelma and Medicine Lodge members in the Cypress Hills section and the shale units in the Castor well also suggest a strong correlation with a facies associated with a more restricted, inshore marine environment. Finally, the proximal, estuarine nature of Tsujita's FA3 and FA4 correspond with the rise in terrestrial influx and decline in assemblage size and diversity recorded in Oxarart interval of the Cypress Hills section and the First and Second Castor Sandstones.

7.3 SYNTHESIS AND BIOSEQUENTIAL INTERPRETATION

The relative abundance, diversity and dominance within dinocyst assemblages are powerful tools for the interpretation of palaeoenvironments and sequence stratigraphic

events, particularly when considered in combination with lithofacies and palaeotemperature.

7.3.1 Cypress Hills Section

The positive trends in the G:P ratios and number of species recovered from strata encompassed by chron 33n suggest that the initial incursion of the Bearpaw Sea into the Cypress Hills was composed of two transgressive pulses: a small event recorded in the assemblages recovered from the Manyberries outcrop preceding the main flooding episode in the upper half of chron 33n in the RCA Thelma borehole. In the first flooding event a high amount of terrestrial influx as recorded by S:D values likely influenced the strongly peridinoid-dominant dinocyst flora, possibly through a decrease in salinity, increase in turbidity or other habitat conditions that made the marginal environment suitable for tolerant peridinoid taxa. During the second inundation, the dinocyst flora diversified from being dominated by peridinialean taxa to one where gonyaulacacean taxa were present in equal to near-equal numbers in an open offshore neritic setting. The acme within this positive episode in the middle of chron 33n (sample 4352) is correlated with a low point in terrestrial influx as recorded by the S:D plot (Figure7.5).

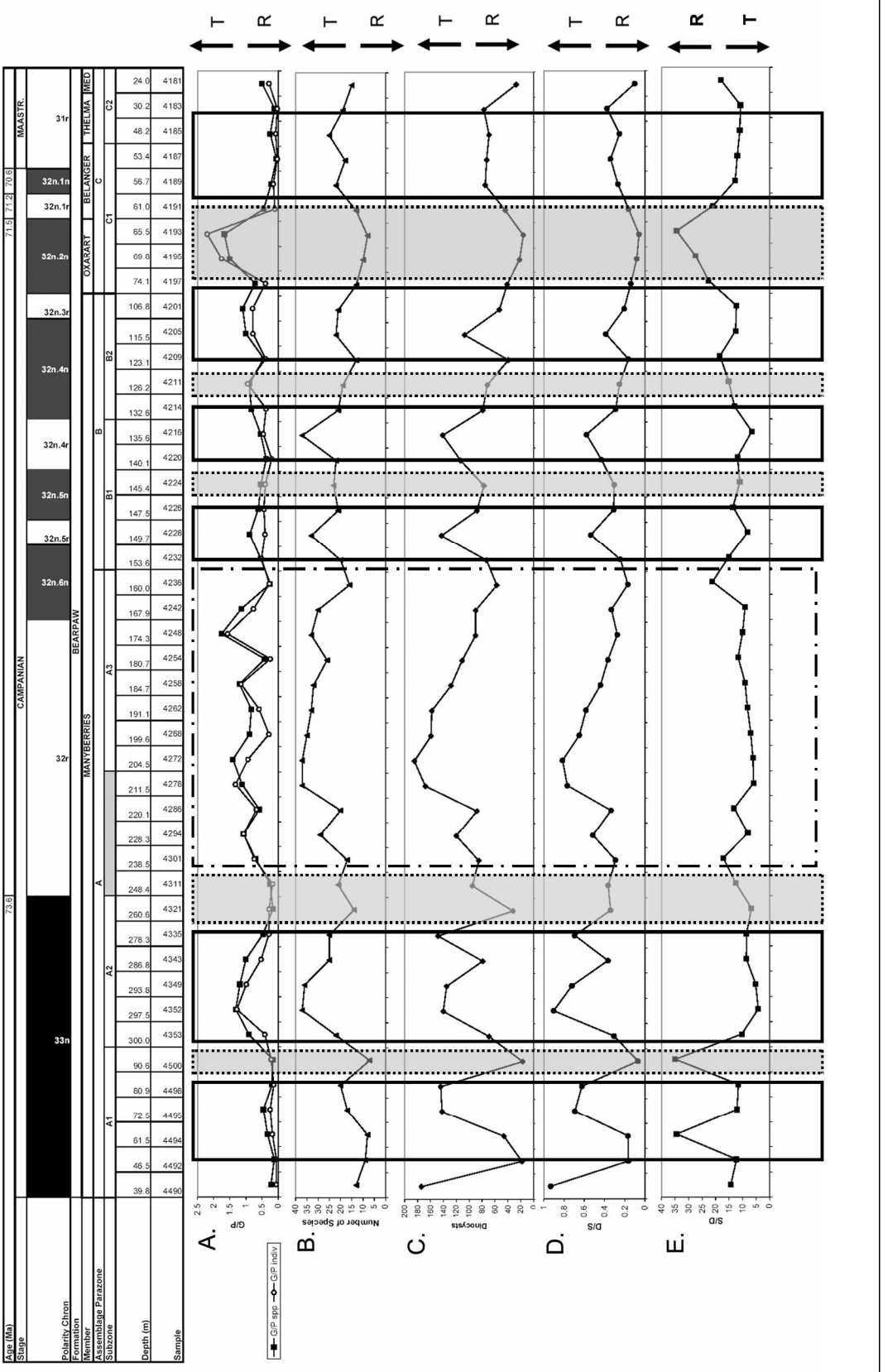
The decline in G:P ratio, recovered species and individual dinocysts in the 33n-32r transition is accompanied by a slight increase in terrestrial influx. This may indicate a temporary regression of the Bearpaw Sea, leading to more inner neritic conditions and increased continental run off delivering more terrestrial palynomorphs and freshwater into the area. Similar declines in the assemblage with an increase in terrestrial influx occurs to a lesser extent in sample 4286 and to a greater extent in samples in the upper

part of chron 32r, lower part of subchron 32n.6n and subchron 32n.4n in the Manyberries Member and in the base of the Oxarart Member in subchron 32n.2n.

The basal 32r regression gives way to a period of increased diversity in numbers of species and dinocysts, decreased terrestrial influx and a gonyaulacacean-dominated flora, reaching a peak in diversity and G:P ratios in the middle of chron 32r, suggesting a period of highstand, open-marine conditions to the end of the chron, followed by a series of gradual regressive pulses and moderately increasing amounts of terrestrial influx indicated by troughs in G:P ratios, numbers of species and numbers of cysts in subchrons 32n.6n, 32n.5n and 32n.4n in the Manyberries Member. These regressive conditions persist throughout the rest of the section, with conditions more suited to flora dominated by peridinialean taxa through the Oxarart, Belanger, Thelma, Medicine Lodge members in subchron 32n.2n through chron 31r. The assemblages recovered from the Belanger, Thelma and Medicine Lodge members (subchron 32n.1r through chron 31r) are more diverse than those found in the terminal Oxarart Member with flora dominated by peridinialean taxa in habitats experiencing a moderate amount of terrestrial influx.

The peak in both G:P ratios in the upper Oxarart Member in subchron 33n.2n differs dramatically from the previous peaks in showing an inverse relationship between the numbers of species and dinocysts recovered and a strong correspondence with the peak in terrestrial influx. The assemblages recovered from the interval (samples 4193 and 4195) were found to be in a poor state of preservation with a very heavy phytoclast content. Considering the small number of dinocysts recovered and their poor state of preservation, the actual prevalence of gonyaulacacean taxa in this interval is somewhat speculative, particularly when the inverse relationship between the numbers of species

Figure 7.5: Interpretation of transgressive and regressive episodes based on semi-quantitative analyses of dinocyst taxa recovered from the composite Cypress Hills section, correlated with the magnetostratigraphy of Lerbekmo and Braman (2002). Boxes with solid black lines indicate transgressive episodes; boxes with dotted lines and grey shading indicate regressive episodes; and box with dotted and dashed outline indicates high stand conditions. A. G:P ratios; B. Number of species per sample; C. Number of dinocysts per sample; D. D:S ratio; E. S:D ratio. Arrows indicate transgression (T) and regression (R). 'Maastr.' = Maastrichtian. 'Med.'= Medicine Lodge Member. Ages of magnetochrons from Ogg and Smith (2004).


Age (Ma)
Stage
Polarity Chron
Formation
Member
Assemblage Parazone
Subzone
Depth (m)
Sample
MAASTR.
CAMPANIAN
71.5
71.2
70.6
73.6
31r
32n.1n
32n.1r
32n.2n
32n.3r
32n.4n
32n.4r
32n.5n
32n.5r
32n.6n
32r
33n
BEARPAW
MANYBERRIES
OXARART
BELANGER
THELMA
MED
C
C1
C2
B
B1
B2
A
A1
A2
A3
24.0 4181
30.2 4183
48.2 4185
53.4 4187
56.7 4189
61.0 4191
65.5 4193
69.6 4195
74.1 4197
106.8 4201
115.5 4205
123.1 4209
126.2 4211
132.6 4214
135.6 4216
140.1 4220
145.4 4224
147.5 4226
149.7 4228
153.6 4232
160.0 4236
167.9 4242
174.3 4248
180.7 4254
184.7 4258
191.1 4262
199.6 4268
204.5 4272
211.5 4278
220.1 4286
228.3 4294
238.5 4301
248.4 4311
260.6 4321
278.3 4335
286.8 4343
293.8 4349
297.5 4352
300.0 4353
90.6 4500
80.9 4498
72.5 4495
61.5 4494
46.5 4492
39.8 4490
T
R
A.
G/P
GP spp
GP indiv
B.
Number of Species
C.
Dinocysts
D.
D/S
E.
S/D

and cysts recovered and the terrestrial influx is consistent with other observations from the rest of the section and the Castor well.

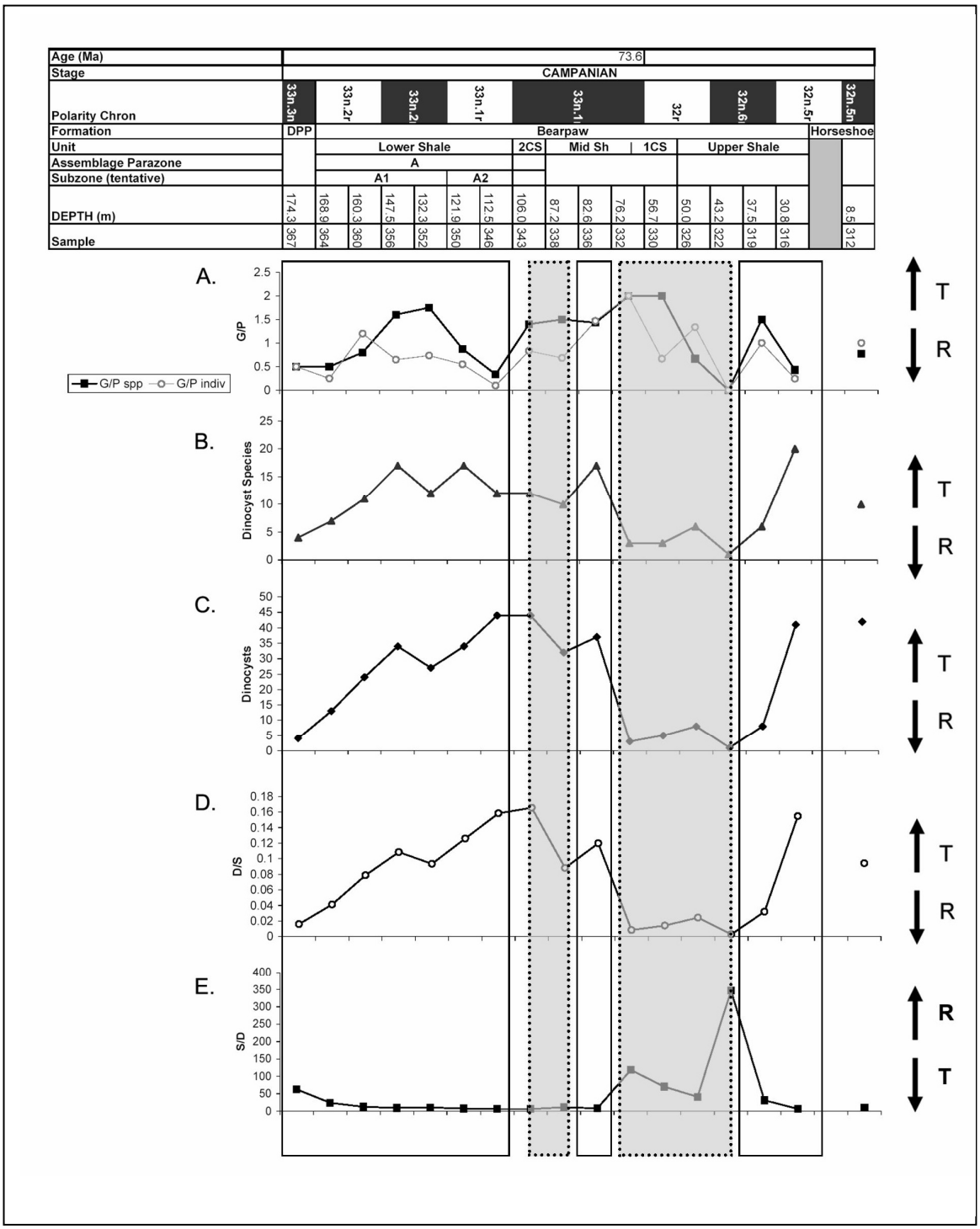
7.3.2 Castor section

The location of the Castor well to the north and west of the Cypress Hills at the landward margin of the of the Bearpaw Sea in central Alberta restricted the deposition of the Bearpaw Formation in the area to chrons 33n, 32r, and subchrons 32n.6n and 32n.5r, equivalent to the lower two thirds of the Manyberries Member in the Cypress Hills. This resulted in a more marginal environment susceptible to a much higher degree of terrestrial influx as well as to regressive pulses of the seaway. This is supported by the facies associations of Tsujita and Westermann (1998) and in the deposition of the First and Second Castor Sandstones. However, the small sample sizes of many of the recovered assemblages limit their reliability as a sequence stratigraphic signal.

The dinocyst succession within the Castor well records a fairly rapid flooding that inundated the underlying Dinosaur Park Formation from subchron 33n.3n through 33n.2n, indicated by increases in G:P_{sp} and the number of species and cysts per sample (Figure 7.6). This transgression results in a diverse, gonyaulacacean-dominated flora in the middle of the lower shale unit in the upper part of subchron 33n.2n. This flooding episode and transgressive peak likely correlates with the second peak seen in chron 33n in the Cypress Hills section.

The D:S ratio and number of dinocysts recovered remains high through the start of deposition of the 2CS but declines through the interval into the middle shale unit. A slight rise is noted in the upper part of subchron 33n.1n (sample 336) prior to a sharp decline in diversity and D:S ratio, with a corresponding increase in the S:D ratio,

Figure 7.6: Interpretation of transgressive and regressive episodes based on semi-quantitative analyses of dinocyst taxa recovered from the RCA Castor core, correlated with the magnetostratigraphy of Lerbekmo et al. (2003). Boxes with solid black lines indicate transgressive episodes; boxes with dotted lines and grey shading indicate regressive episodes. A. G:P ratios; B. Number of species per sample; C. Number of dinocysts per sample; D. D:S ratio; E. S:D ratio. Arrows indicate transgression (T) and regression (R). DPP = Dinosaur Park Formation; 1CS = First Castor Sanstone; 2CS = Second Castor Sandstone. Ages of magnetochrons from Ogg and Smith (2004).


Age (Ma)
73.6
Stage
CAMPANIAN
Polarity Chron
33n.3n
33n.2r
33n.2
33n.1r
33n.1
32r
32n.6
32n.5r
32n.5n
Formation
DPP
Bearpaw
Horseshoe
Unit
Lower Shale
2CS
Mid Sh
1CS
Upper Shale
Assemblage Parazone
A
Subzone (tentative)
A1
A2
DEPTH (m)
174.3 168.9 160.3 147.5 132.3 121.9 112.5 106.0 87.2 82.6 76.2 56.7 50.0 43.2 37.5 30.8 8.5
Sample
367 364 360 356 352 350 346 343 338 336 332 330 326 322 319 316 312
A.
G/P
G/P spp
G/P indiv
B.
Dinocyst Species
C.
Dinocysts
D.
D/S
E.
S/D
T
R
T
R
T
R
T
R
R
T

coinciding with the deposition of the 1CS at the transition in chron 32r. The deposition of the 1CS is likely the result of the same regressive event recorded in the 33n-32r regression in the Cypress Hills, but is more extreme here owing to the Castor well's more proximal location.

Conditions remain closed and marginal in the upper shale unit throughout subchron 32n.6n, although peridinoid taxa make a strong resurgence in chron 32n.5r, as indicated by the positive excursion in species and dinocysts per sample and decrease in G:P ratio at 30.8 m (sample 316). A similar upswing is present in the same subchron in the Cypress Hills section at 148 m (sample 4226), indicating a transgressive episode.

7.4 Comparison between the Cypress Hills and Castor sections

Both the composite Cypress Hills section and the RCA Castor core strongly reflect the signal of the initial transgressive phase of the Bearpaw Sea into southern Alberta. This is expressed in both sections as positive trends in G:P ratios, numbers of species and individual cysts recovered per sample and in the D:S ratio during chron 33n (illustrated in Figures 7.5 and 7.6). This transgressive episode consists of two distinct flooding events. The first, occurring in assemblage subzone A1, may be the final instance of the transitory transgressive pulses observed by Brinkman et al. (2005) who reported instances of marine microvertebrate and palynomorph assemblages within the Lethbridge Coal Zone of the Dinosaur Park Formation. The second, larger event is considered to be the transgression that brought the Bearpaw Sea fully into the study area, inundating it for the remainder of the Campanian.

While the distinctive signals of these two flooding events are most readily observable in the Cypress Hills section they are also discernable within the Castor well.

However, the greater proximity to the palaeoshoreline to the Castor well results in a stronger shallowing effect and environmental overprint on the diversity of the recovered assemblages.

For example, the first transgressive pulse is observable in the Castor section as increases in numbers of species and dinocysts per sample from the contact with the Dinosaur Park Formation in subchron 33n.3n through the bottom half of the lower shale unit in the base of subchron 33n.2n. This is also accompanied by a positive trend in G:P_{sp} ratio. The subsequent regressive phase is recorded as slight decreases in D:S ratio and in species and cysts per sample, with the second transgressive event recorded in the return to positive trends in the dinocysts per sample and D:S ratio.

Although these two positive trends continue, they are decoupled from the G:P ratios and the number of species. This apparent contradiction can be explained by the increased influx of terrigenous clastics that were deposited as the 2CS. This clastic input, although it appears to occur during a larger transgressive interval, would presumably have altered the local environment, increasing turbidity and delivering nutrients in the form of organic particles of terrestrial origin. These turbid conditions likely be unsatisfactory for autotrophic gonyaulacacean taxa, but would have provided an ample nutrient supply for heterotrophic peridinialean taxa. With the termination of the clastic sediments, deposition of the 2CS ceased and the dinocyst population diversified as conditions became more suitable to a broader range of taxa, as appears to be the case in the subsequent assemblages recovered from the middle shale unit.

A regressive event is apparent in the uppermost part of chron 33n in the Cypress Hills and is recorded in subchron 33n.1n in the Castor well, in both sections near the

contact with chron 32r. In the Cypress Hills, this shallowing is indicated by a decrease of the G:P ratios, the numbers of species and cysts per sample and the D:S ratio, coupled with an increase in S:D ratio. Within the Castor section, the regression signal is strongly apparent as abrupt decreases in recovered species and individuals and in the D:S ratio, coinciding with a spike in S:D ratio. Lithologically, the event is also recorded by the deposition of the 1CS. The combination of regressive conditions and high terrestrial influx had a major impact on the microplankton population, with the lowest number of taxa recovered in the study occurring in the interval including and immediately following the 1CS. This low recovery also makes the G:P ratios within this interval unreliable. A subsequent transgression is apparent in both sections as a positive trend that can be observed in subchron 32n.6n into 32n.5r, after which core recovery was lost in the Castor well.

The comparison and correlation of events of the distal Cypress Hills section with the more proximal Castor section permit the tracing of sequence stratigraphic events:

- A transitory transgressive pulse, followed by a substantive transgression in the lower part of chron 33n, accompanied by increases in the number of species, cysts and G:P ratios;
- A regression in the uppermost part of chron 33n (recorded as subchron 33n.1n in Castor) through the lower part of chron 32r, reflected in the microplankton population by declines in species, individual cysts and (in the case of the Cypress Hills succession) a decrease in G:P ratio, indicating an abundance of a low diversity assemblage of largely heterotrophic, peridinialean taxa;

- A more gradual transgression, consisting of a series of transgressive-regressive couplets, through chron 32r and subchron 32n.6n. The recovery of the Castor succession is dampened due to its proximity to the shoreline and higher degree of terrestrial influx. The transgression episodes continue into subchron 32n.5n and 32n.4n in the Cypress Hills section, but are lost in the Castor well.

A sequence stratigraphic signal may also be traced through the remainder of the Cypress Hills section. An overall decline in the number of species and cysts occurs after the acme observed in subchron 32n.4n in the uppermost Manyberries Member followed by a sharp decline in G:P_{sp} ratio and the numbers of species and cysts. A small rally in the vicinity of the boundary between the Manyberries and Oxarart members is followed by a shallow trough in the number of species and cysts, accompanied by a steady increase in the S:D ratio which may coincide with the deposition of the sandstones within the Oxarart and Belanger members. A gradual increase and plateau in the Belanger and Thelma members is offset by very low G:P values through the top of the core, suggesting that a long period of lowstand conditions created an estuarine environment suitable for a large flora dominated almost exclusively by peridinialean taxa.

7.5 COMPARISON WITH OTHER REPORTS FROM THE BEARPAW FORMATION OF ALBERTA

7.5.1 Castor Microfauna

In their study of the microfauna recovered from the Castor well, Given and Wall (1971) provided a palaeoenvironmental interpretation based on the relative proportions of

agglutinated to calcareous foraminifera. They found that the section was generally characterized by agglutinated taxa, indicating a marginal marine environment. However, they also identified five episodes characterized by increases in the relative abundance of calcareous foraminifera and a "modest increase" overall in taxa which they interpreted as instances of more open marine conditions (*op. cit.* p. 519). Three of the episodes occurred in the lower shale unit, one in the middle shale and one in the upper shale above the 1CS.

At least two deepening episodes are apparent in the dinocyst assemblage from the lower shale unit (Figure 6.4). The first of the episodes, reported by Given and Wall (1971) at approximately 160 m, corresponds with the positive excursions observed in G:P_{sp}, number of species and number of cysts recovered in samples 364 and 360. The acmes in the dominance of calcareous foraminifera that occurs between 152 and 144 m conforms well to the peaks observed in species per sample and G:P_{sp} in the same position in the core. A similar correlation can be made between the foraminifera assemblages within the middle shale unit with the dinocyst assemblages from the same levels within the borehole. There, the calcareous-dominant fauna reported by Given and Wall (1971) between 90 and 77 m corresponds to the peak in the dinocyst assemblage's semi-quantitative measurements in sample 336 (82.6 m).

The fifth episode of deepening, posited by Given and Wall (1971) as being of a short duration, is not readily apparent within the dinocyst succession, possibly due to differences in sampling and poor recovery from the interval. However, the sudden change to a microfauna almost completely dominated by agglutinated forms does seem to correspond to the development of the peridinoid-dominant flora that was observed at the top of the upper shale interval.

7.5.2 Lethbridge and Cypress Hills

In his report of dinocysts and acritarchs from the Bearpaw Formation, Harland (1973) used semi-quantitative analyses including the G:P_{sp} ratio, number of dinocysts per sample and the percentage of phytoplankton per sample to interpret the depositional environment. He found that an increase in the percentages of phytoplankton (dinocysts and acritarchs) was accompanied by an increase in species and increase in the G:P_{sp} ratio, which he proposed as indicators of relatively open marine conditions (*op. cit.*, p. 701). He proposed that an initial transgression was recorded in the lowermost 45 m of the section, with "optimum open marine conditions" occurring between 18 and 30 m above the base of the section. Two subsequent periods of open conditions were also identified between 55 and 73 m and 95 and 107 m above the base of the section, respectively.

Harland (1973) compared the semi-quantitative analyses of his recovered assemblages from the Lethbridge section with the foraminiferan microfauna reported by Anan-Yorke (1969). Anan-Yorke (1969) had interpreted the microfauna within the section in terms of five facies zones: (1) basal 17 m – brackish lagoonal; (2) 17 to 35 m – open marine; (3) 35 to 60 m – brackish lagoonal; (4) 60 to 137 m – deeper water ("but not as deep as 2," Harland, 1973, p. 701); and (5) 137 m to the base of the Ryegrass Member – lagoonal. Harland (1973) found that the optimal period of open marine conditions within his assemblage correlated with Anan-Yorke's facies zone 2 and fluctuating conditions equivalent to Anan-Yorke's zone 5.

Although Harland (1973) did not carry out a detailed comparison between the semi-quanitative results for his Lethbridge and Cypress Hills section from the RCA Thelma well, positive trends in G:P ratio and dinocysts per sample within the Cypress

Hills section corresponded with those that recorded the initial transgression within the Lethbridge section, along with other periods of open marine conditions. A detailed comparison between the $G:P_{sp}$ ratio and dinocyst per sample plots obtained in this study and those reported by Harland (1973) for the Cypress Hills section is not possible due to differences in sampling and counting, although strong similarities exist. These include a correlation between the initial positive trend in Harland's plots of dinocysts per sample and $G:P_{sp}$ and the second positive trend locate in parazone A2 in this study (both equate to the base of the RCA Thelma core), as well as positive trends in the middle third of the Manyberries Member in the vicinity of this study's parazone A3. The peaks in dinocysts per sample in parazone B1 in the uppermost Manyberries Member and increase in dinocysts per sample and $G:P_{sp}$ ratio in parazone B2 immediately below the Oxarart Member are also apparent. This suggests that the signals reported in both studies do in fact reflect the same transgressive and regressive events.

7.5.3 Central Alberta and Rocky Mountain Foothills

Kurita and McIntyre (1994) included an interpretation of the depositional environment for their dinocyst assemblages from the Bow River valley (identified by them as the "Bow River," "Bassano South," and "Bassano Southeast" localities) and from the Longview Section in the foothills southwest of Calgary. Within the Bow River section, a proliferation in species and an increase in diversity in the lower Bearpaw strata was indicative of a rapid transgressive event that resulted in a marginal, peridinoid dominated assemblage giving way to a relatively gonyaulacacean-enriched population in the upper part of the interval. This was interpreted as relatively rapid transition from marginal embayment to a more open marine nearshore environment to a shelf (*op. cit.* p.

73). The assemblages recovered from the Bassano South locality were relatively sparse and declined upward, suggesting that the retreat of marine conditions occurred throughout the interval. The Bassano Southeast assemblages were reported as an intermediate between the two other localities and led to the conclusion that the lower part of the Bearpaw Formation within the upper Bow River valley was deposited during peak transgression. This interpretation would suggest that the Bearpaw Formation in the area was deposited contemporaneously with the lower half of the Manyberries Member in the Cypress Hills section.

The assemblages recovered from the Longview section in the foothills were reported to be dominated by terrestrial sporomorphs throughout most of the interval, with peridinoid cysts being consistently dominant amongst the dinocyst population. This would suggest a more restricted, marginal marine situation, which was considered to be "consistent with the marginal location of the section within the basin" close to the westernmost extreme of the Bearpaw cyclothem (Kurita and McIntyre, 1994, p. 74), while the Cypress Hills section was deposited in deeper water.

8.0 CONCLUSIONS

Marine palynomorph assemblages consisting of 34 genera and 69 species of dinoflagellate cysts and 8 forms of acritarchs were recovered from a composite section in the Cypress Hills and the RCA Castor core of southern Alberta. The assemblages were deposited as part of the eastward-thickening Bearpaw Formation during the transgression and regression of the Western Interior Seaway as the Bearpaw cyclothem during the Latest Campanian and Early Maastrichtian. The studied sections occupied an embayment of the Bearpaw Sea, with the Cypress Hills section located distally to seaward and the Castor section located proximally to the embayment's northwest margin.

Correlation of the relative abundances, first and last occurrences of taxa and semi-quantitative measures of the assemblages with magnetostratigraphic data and radiometric age dates of bentonites within the Bearpaw Formation resulted in the erection of three parazones and six subzones within the Cypress Hills section with chronostratigraphic controls. These controls also permitted correlation of the Cypress Hills section with the Castor section, and by extension the Campanian-Maastrichtian Global Stratotype Section and Point at Tercis les Bains, France via the Botticione section in Italy (Lewy and Odin, 2001). A comparison of first and last occurrence data of stratigraphically-significant taxa found to be in common between the microplankton succession recovered in this study and at Tercis (Antonescu et al., 2001b) supports the magnetostratigraphic position of the Campanian-Maastrichtian boundary at the transition from magentosubchron 32n.1n to

magnetochron 31r, within the *Baculites baculus* ammonite zone in the Western Interior of North America as proposed by Lerbekmo and Braman (2002).

Semi-quantitative analyses including the relative abundances of gonyaulacacean to peridinoid taxa, expressed as G:P ratios; the number of species of dinocysts recovered and the number of individual dinocysts recovered as proxies for diversity and dominance within the assemblage; and the proportions of marine palynomorphs to terrestrial palynomorphs as a proxy for terrestrial influx all record the sequence of transgression and regression within the Bearpaw cyclothem. Increases in G:P ratios, assemblage diversity (expressed as increases in numbers of species and individual cysts) and the value of the ratio of dinocysts to terrestrial sporomorphs are interpreted as recording transgressive episodes, whereas decreases in the same semi-quantitative values accompanied by an increase in terrestrial influx indicate the onset of regressive conditions.

The Cypress Hills and Castor sections both record the initial inundation of the Bearpaw Sea into eastern and central Alberta. Two separate peaks in G:P_{sp} ratio and numbers of species and individual dinocysts in the base of the Manyberries Member in chron 33n of the Cypress Hills section record two flooding events, a smaller transgressive pulse followed by a larger inundation an onset of open marine conditions within the section through the period of peak transgression of the cyclothem during the interval of the *Baculites compressus, B. cuneatus* and *B. reesidei* ammonoid range zones. A proximal retrenchment observed as declines in G:P ratios and microfloral diversity is also apparent in both sections in the vicinity of the 33n-32r transition, and is also recorded by the deposition of the First Castor Sandstone in the Castor well. A return to more distal conditions in the upper part of the Manyberries Member and the Upper Shale Unit in the

Castor well gives way to marginal conditions in both sections, observable as flattening of semi-quantitative trends and increases in terrestrial influx. Within the Castor section, this is recorded as the onset of nearshore, prodeltaic conditions and end of Bearpaw deposition. In the Cypress Hills, it is recorded as more confined, inner-neritic conditions leading to a microflora dominated by peridinoid taxa. This interpretation is supported by lithofacies associations and molluscan palaeoecology (Tsujita, 1995a; Tsujita and Westermann, 1998), $\delta^{18}O$ palaeotemperature estimates (He et al., 2005) foraminiferan palaeoecology (Given and Wall, 1971; Anan-Yorke, 1969) and microvertebrate studies (Brinkman et al., 2005).

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APPENDIX A. LITHOLOGICAL DESCRIPTIONS

Research Council of Alberta Thelma WTH 14-31-6-2W4

Collected and logged by J.H. Wall November, 1969

Sampled by D.R. Braman, 1989 (TMP DB 89-1). Splitted November 20, 2002

Sample	Description	Depth (m)	Remarks
4181	"Shale, dark grey, soft, bentonitic; lenses of grey and yellow sand; trace coal"	24.0 – 24.7	Medicine Lodge Mbr; DB 89-1-02
4183	"Shale, medium grey speckled with darker grey, blocky with a few lines of grey silt."	30.2 – 30.8	Thelma Mbr; 89-1-04
4185	"Sand, yellow, compact, fine grained with several 1 inch bands of dark grey, bentonitic shale"	48.2 – 50.3	89-1-06
4187	"Shale medium grey, wafery with lenses of silt."	53.4 – 54.6	Belanger Mbr; 89-1-08
4189	"Shale, medium grey, firm, massive to wafery, somewhat silty throughout; 2-inch band of silt at 1 foot from top; some fracturing or slickensiding near middle."	56.7 – 58.8	89-1-10
4191	"Shale, medium grey, hard, blocky, massive to wafery, silt lenses."	61.0 – 63.4	89-1-12
4193	"Shale, medium grey, firm, mostly massive, quite sandy with many lenses of sand and silt; a few weathered shell fragments."	65.5 – 67.7	Oxarart Mbr; 89-1-14
4195	"Shale, medium grey, firm, massive to wafery, fairly sandy with lenses and burrowings (sic)."	69.8 – 72.0	89-1-16
4197	"Shale, medium grey, somewhat silty."	74.1 – 76.2	89-1-18
4201	Shale and siltstone, light olive grey	106.8-108.8	Manyberries Mbr
4205	Shale, dark olive green, silty, massive	113.1-115.5	

4214	Shale, medium green	132.6-134.3	
4216	Shale, medium green, few patches of lighter silt	135.6-136.9	
4220	Shale, medium green, massive and somewhat silty	140.1-141.1	
4224	Shale, medium green, silty, with pyrite stringers	145.4-146.5	
4226	Shale, medium to dark green, some bluish green	147.5-148.6	
4228	Same as above with bentonite and pyrite stringers	149.7-150.7	
4232	Shale, light to medium olive grey, some pyrite stringers	153.6-154.7	
4236	Shale, medium green, hard	160.0-162.2	
4242	Shale, medium to dark green, massive	167.9-169.0	
4248	Shale, dark green, massive	174.3-175.4	
4254	Shale, medium olive grey	180.7-181.7	
4268	Shale, medium to dark green, massive and hard	199.6-200.9	
4272	Shale, medium green	204.5-205.7	
4278	Shale, light to medium green, some silt and pyrite	211.5-212.6	
4286	Shale, medium green, hard	220.1-221.1	
4294	Shale, medium green, hard and silty	228.3-230.5	
4301	Shale, medium green, soft	237.4-238.5	
4311	Shale, medium green, medium hard	248.4-249.5	
4321	Shale, medium to dark green, silty	260.6-261.5	
4335	Shale, light to medium green	278.3-279.5	
4343	Shale, medium green, hard and silty	286.8-287.9	
4349	Shale, medium to dark green	291.4-292.6	
4352	Shale, medium green, hard lenses	297.5-298.7	
4353	Shale, medium green	298.7-299.99	END DB 89-1-173

Surface Collection, Southeast of Manyberries, Alberta 7-35-4-5W4 to 10-23-4-5W4

Base: UTM 12:0530668; 5465166 Top: UTM 12:0530668; 5454103 (NAD83)

Collected 21 July 21, 2003

Sample	Description	Height (m)	Remarks
4490	Siltstone, dark olive grey	39.8	2 m above upper Lethbridge Coal
4492	Shale, olive grey	46.5	
4495	Shale, olive grey	72.5	
4498	Shale, olive grey	80.9	
4500	Shale, olive grey	90.6	TOP OF SECTION

Research Council of Alberta Castor WTH 13-34-37-13W4

Logged by J.H. Wall 1971. Sampled and splitted by A. Sweet, 1998 (GSC P-4443)

Sample	Description	Depth (m)	Remarks
401312	"Shale, black, carbonaceous"	8.5 – 8.7	Horseshoe Canyon Formation
401316	"Shale, brownish grey, dark grey, soft, bentonitic in part, wafery"	30.8 – 32.9	Bearpaw Formation contact 29.8 m
401319	"Shale, medium to dark grey, bentonitic in part, some silty laminae and carbonaceous material"	35.4 – 37.5	
401322	"Shale, medium grey, …bentonitic in part and silty"	41.8 – 43.6	
401326	"Shale, medium to dark grey, some bands of fairly sandy material; occasional bentonitic shale and carbonaceous fragments."	47.9 – 50.0	
401330	"Shale, medium to dark grey, bentonitic, especially in lower foot."	54.6 – 56.7	1CS contact 55.3 m
401332	"Shale, dark grey, waxy lustre, apparently bentonitic in part, with some bands of light grey siltstone and occasional thin buff clay band."	76.2 – 78.3	Base of 1CS 73.5 m
401336	"3'6" - Shale, dark grey…[changing to] 4'6" – Siltstone, light to medium grey, lenses and laminae of shale."	82.6 – 85.0	
401338	"Shale, dark grey, silty lenses and shell fragments; 3 inch bed of [light] greenish bentonite 2 feet from bottom."	87.2 – 89.0	2CS upper contact 95.7m
401343	"Shale, dark grey, waxy lustre, bentonitic with occasional sand lenses; pelecypods."	106.1 – 108.2	Base of 2CS 106 m
401346	"Shale, mostly dark geyr, bentonitic, not noticeably silty."	112.5 – 113.2	
401350	"Shale, dark grey, bentonitic, with lenses of green, medium-grained sand."	121.9 – 124.1	
401352	"Sandstone, greenish-grey, fine-grained and compact, with irregular interbeds of dark, bentonitic shale."	132.3 – 133.8	

401356	"3'0" – Sandstone, greenish-grey, fine-grained, argillaceous; large shells; 5'0" – Shale, medium to dark grey, conchoidal fracture, sand lenses in upper part becoming cleaner with depth; occasional bentonite patch"	147.5 – 149.7	
401360	"Shale, medium to dark grey, slightly to moderately sandy, shell fragments"	160.3 – 162.5	
401364	"Shale, medium to dark grey, blocky-massive to wafery, lenses of fine-grained sand and laminae of light grey silt; occasional bentonitic bands, clayey material; fossils"	168.9 – 171.3	
401367	"Shale, dark greyish-brown to black, fissile, carbonaceous with bands of coal."	174.3 – 175.3	Dinosaur Park Fm (contact 173 m)

APPENDIX B. PALYNOLOGICAL COUNTS

Figure B-1: Complete counts of marine and terrestrial palynomorphs recovered from the RCA Castor core.

Age (Ma)																		
Stage	CAMPANIAN																	
Polarity Chron	33n.3n	33n.2r		33n.2n	33n.1r	33n.1n					32r	32n.6n		32n.5r				32n.5n
Formation	DPP	Bearpaw																Horseshoe
Member		Lower Shale					2CS	Mid Sh			1CS	Upper Shale						
Assemblage Parazone		A																
Subzone		A1				A2												
DEPTH (m)	174.3	168.9	160.3	147.5	132.3	121.9	112.5	106.1	87.2	82.6	76.2	56.7	50.0	43.2	37.5	30.8		8.5
Sample	367	364	360	356	352	350	346	343	338	336	332	330	326	322	319	316		312
Alterbidinium cf. *montanense*																2		2
Chatangiella decorosa							5									3		6
Isabelidinium cooksoniae		1	1			1	2									1		1
Leberidocysta chlamydata													1					1
Cerodinium cf. *diebelii*																		2
Palaeoperidinium cretaceum		1		1	4	3	10		7	4				1	2	4		12
Palaeoperidinium parvum					2		6		4	2	1					1		5
Palaeoperidinium pyrophorum			1	1			5			1						4		6
Laciniadinium arcticum	1	5	2	7	3	4		9	7	3		3	1			1		2
Circulodinium distinctum					1	2		2	2	1								5
Alterbidinium acutulum						3	2								1	7		
Chatangiella biapertua							1									2		
Chatangiella granulifera													1			2		
Isabelidinium microarmum							3											
Laciniadinium firmum			4	6	6	2		10		2						1		
Laciniadinium biconiculum				2				1								1		
Microdinium cf. *ornatum*							1	6	3	1					1	1		
Spongodinium delitiense	1									2	1					1		
Spiniferites ramosus			1	1				1		1						1		
Spiniferites pseudofurcatus										1					1	1		
Hystrichosphaeridium tubiferum var. *brevispinum*				1	1							1				2		
Oligosphaeridium pulcherrimum				1	2	2		1	3	3						2		
Isabelidinium acuminatum	1					4										2		
Tanyosphaeridium variecalum			2					1	1							2		
Dinogymnium acuminatum		3	1	2									1		2			
Downiesphaeridium sp. A			6	2											1			
Hystrichosphaeridium arborispinum				1						2			2					
Odontochitina operculata		1	1			1			2	6	1		2					
Achomosphaera ramulifera										4		1						
Spinidinium clavus		1				2		3		2								
Eucladinium spinossinum										1								
Dapsilidinium marinum		1		1	2			5		1								
Criboperidinium exilicristatum					2	2	2		1									
Pterodinium cingulatum						1			2									
Downiesphaeridium armatum			4	3	1	2	1	4										
Oligosphaeridium complex				1				1										
Chatangiella ditissima							6											
Dinogymnium digitus				1	1	1												
Dinogymnium longicorne			1	1		2												
Phelodinium tricuspe						1												
Gonyaulacysta cf. *eisenackii*					2	1												
Dinogymnium sibiricum	1			2														
TOTAL DINOCYST	**4**	**13**	**24**	**34**	**27**	**34**	**44**	**44**	**32**	**37**	**3**	**5**	**8**	**1**	**8**	**41**		**42**
ACRITARCHS																		
Palambages morulosa			4	2	3	4	1	4	4	6	2				1	1		1
Fromea fragilis		3	5	4		4		7		1					1	3		
Verryhachium spp.						1										1		
Micrhystridium harlandii					1			7	1	1		1			1			
Michrystridium spp.								3							3			
Fromea chytra			2							1								
TOTAL DINOCYSTS + ACRITARCHS	**8**	**29**	**57**	**74**	**58**	**77**	**89**	**109**	**69**	**82**	**8**	**11**	**16**	**2**	**22**	**87**		**85**
POLLEN & SPORES	245	295	295	300	223	202	255	250	298	228	251	326	170	279	200	190		390
Bisaccates					55	56			57	66	99	24	145	61	50	60		50
Aquilapollenites spp.	6	20	10	13	11	12	23	16	8	15	6	3	14	6		15		6
TOTAL TERRESTRIAL	**251**	**315**	**305**	**313**	**289**	**270**	**278**	**266**	**363**	**309**	**356**	**353**	**329**	**346**	**250**	**265**		**446**
TOTAL PALYNOMORPHS	**267**	**373**	**421**	**461**	**405**	**424**	**456**	**484**	**501**	**474**	**372**	**375**	**361**	**350**	**294**	**439**		**616**
DINOCYSTS PER SAMPLE	4	7	11	17	12	17	12	12	10	17	3	3	6	1	6	20		10
DINOCYST SP PER SAMPLE	4	8	14	19	14	20	13	16	12	21	4	4	6	1	10	23		11
D:S RATIO	0.02	0.04	0.08	0.11	0.09	0.13	0.16	0.17	0.09	0.12	0.01	0.01	0.02	0.00	0.03	0.15		0.09
S:D RATIO	62.75	24.23	12.71	9.21	10.70	7.94	6.32	6.05	11.34	8.35	118.67	70.60	41.13	346.00	31.25	6.46		10.62

Figure B-2: Complete counts of marine and terrestrial palynomorphs recovered from the Cypress Hills composite section.

| | | |

PLATES

Figured specimens are all at 680x magnification unless otherwise stated. Slide locations are given in the format "vertical/horizontal" in mm.

PLATE 1

Figure	Taxon	Slide Location
1	*Dinogymnium acuminatum*	GSC 401356 010/103
2	*Dinogymnium digitus*	GMUS 4335 B 016.2/110
3	*Dinogymnium longicorne*	GSC 401350 015.5/80
4	*Dinogymnium sibiricum*	GSC 401350 015.2/94
5	*Odontochitina operculata* hypocyst	GMUS 4216-1 021.5/105
6	*Hystrichosphaeridium tubiferum*	GMUS 4228-1 008/101.7
7	*H. tubiferum* var. *brevispinum*	GMUS 4278-1 020.3/87
8	*Hystrichosphaeridium arborispinum*	GMUS 4278-1 007.5/105

PLATE 2

Figure	Taxon	Slide Location
1	*Odontochitina operculata* (x500)	GMUS 4262 A 018/116
2	*Odontochitina operculata* operculum	GMUS 4242-1 015.5/114.2

PLATE 3

Figure	Taxon	Slide Location
1	*Criboperidinium exilicristatum*	GSC 401338 004.5/96
2	*Florentinia mantellii*	GMUS 4262 A 024/101
3	*Spongodinium delitiense* (x500)	GMUS 4224 B 021/104.5
4	*Achomosphaera ramulifera*	GMUS 4278-1 013/105

PLATE 4

Figure	Taxon	Slide Location
1	*Pterodinium cingulatum*	GMUS 4244-1 021/101.5
2	*Spiniferites ramosus*	GMUS 4292 A 003/115
3	*Spiniferites ramosus*	GMUS 4272 A 016.5/112
4	*Spiniferites ramosus*	GMUS 4193 008/112
5	*Spiniferites membranaceous*	GMUS 4268-1 019.5/104.8
6	*Fibrocysta vectens*	GMUS 4321 A 106.5/117
7	*Spiniferites pseudofurcatus*	GMUS 4216-1 012.5/107.5

PLATE 5

Figure	Taxon	Slide Location
1	*Circulodinium distinctum*	GMUS 4242-1 006/121
2	*Circulodinium distinctum*	GSC 401338 018/104.2
3	*Downiesphaerdium armatum*	GMUS 4352-1 018.5/111.2
4	*Downiesphaeridium? aciculare*	GMUS 4248-1 010.5/115.8
5	*Downiesphaeridium* sp. A (x 500)	GMUS 4242 A 019.8/105
6	*Downiesphaeridium* sp. A	GMUS 4228-1 012.5/110

PLATE 6

Figure	Taxon	Slide Location
1	*Dapsilidinium marinum*	GMUS 4258-1 012.5/110
2	*Exochosphaeridium* cf. *phragmites*	GMUS 4272-1 003.5/110
3	*Microdinium* cf. *ornatum*	GMUS 4262-1 010.5/102
4	*Prolixosphaeridium parvispinum*	GMUS 4272 A 009/110
5	*Tanyosphaeridium variecalamum*	GMUS 4214A 013.5/103
6	*Gonyaulacysts* cf. *eisenackii*	GMUS 4258-1 013.5/106
7	*Oligosphaeridium complex*	GMUS 4262-1 013.8/105

PLATE 7

Figure	Taxon	Slide Location
1	*Oligosphaeridium anthophorum*	GMUS 4205-2 006.5/100.5
2	*Oligosphaeridium pulcherrimum*	GMUS 4248 A 007/114
3	*Cometodinium* cf. *whitei*	GMUS 4352 A 011.5/112.8
4	*Pervosphaeridium truncatum*	GMUS 4244-1 022/108
5	*Alterbidinium acutulum*	GMUS 4181 007/101.8
6	*Alterbidinium dictyotum*	GMUS 4214 A 011/103
7	*Alterbidinium minus*	GMUS 4186 008/114.1
8	*Alterbidinium* cf. *montanense*	GSC 401316 009.5/95
9	*Alterbidinium* cf. *montanense*	GMUS 4189 021.5/101.8

PLATE 8

Figure	Taxon	Slide Location
1	*Cerodinium* cf. *diebelii*	GMUS 4248 A 016.5/112
2	*Cerodinium pannuceum*	GMUS 4294 A 008.5/111
3	*Cerodinium speciosum*	GMUS 4254 B 013/108

PLATE 9

Figure	Taxon	Slide Location
1	*Chatangiella? biapertua*	GSC 401316 010/91
2	*Chatangiella spectabilis*	GMUS 4189 020.3/101
3	*Chatangiella decorosa*	GMUS 4185 013/116
4	*Chatangiella ditissima*	GMUS 4498 A 017/107
5	*Chatangiella granulifera*	GSC 401315 022/85

PLATE 10

Figure	Taxon	Slide Location
1	*Chatangiella tripartita*	GMUS 4278 A 006/164
2	*Chatangiella turbo*	GMUS 4498 A 017/115
3	*Eucladinium spinosissimum*	GSC 401346 019/80

PLATE 11

Figure	Taxon	Slide Location
1	*Isabelidinium korojenense*	GMUS 4224 B 011.8/113
2	*Isabelidinium acuminatum*	GMUS 4205-1 012/113.5
3	*Isabelidinium* cf. *cooksoniae* (x500)	GMUS 4242-1 013/107.5
4	*Isabelidinium belfastense*	GMUS 4185 008/102.8
5	*Senegalinium bicavatum*	GMUS 4224 A 017.4/108
6	*Senegalinium obscurum*	GMUS 4236 A 016/106

PLATE 12

Figure	Taxon	Slide Location
1	*Spinidinium clavus*	GMUS 4220 A 015/99.6
2	*Spinidinium echinoideum*	GMUS 4220 B 013/108
3	*Trithyrodinium evittii*	GMUS 4186 018.5/110.5
4	*Trithryodinium suspectum*	GMUS 4352 A 011/102
5	*Leberidocysta chlamydata*	GSC 401326 007/87
6	*Laciniadinium arcticum*	GMUS 4349 A 016.2/114.2
7	*Laciniadinium biconiculum*	GMUS 4268 012.5/112
8	*Laciniadinium firmum*	GSC 401360 021.5/107
9	*Isabelidinium microarmum*	GMUS 4278 A 012/105.4

PLATE 13

Figure	Taxon	Slide Location
1	*Palaeoperidinium pyrophorum*	GMUS 4228 A 010/112.4
2	*Palaeoperidinium cretaceum*	GMUS 4242 A 019.5/120
3	*Palaeoperidinium parvum*	GMUS 4278 A 018/109
4	*Phelodinium magnificum*	GMUS 4352 A 020.5/107

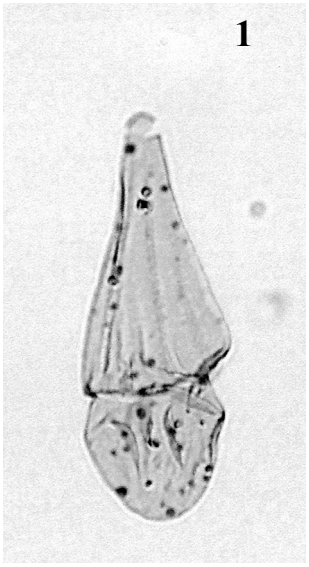
PLATE 14

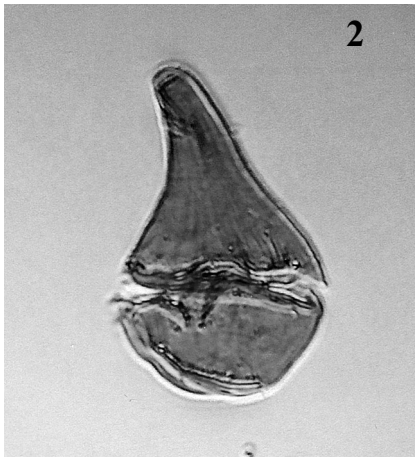
Figure	Taxon	Slide Location
1	*Phelodinium tricuspe*	GMUS 4236 A 013/100.2
2	Dinoflagellate sp. 1 Holotype	GMUS 4490 A021/116
3	Dinoflagellate sp. 1	GMUS 4490 A 010/115

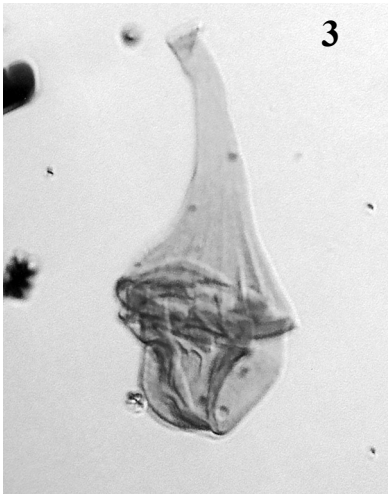
PLATE 15

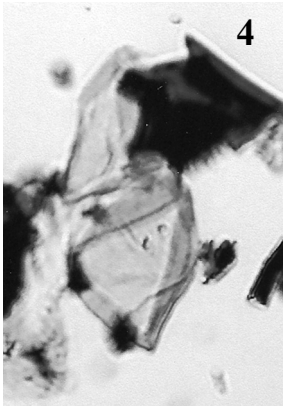
Figure	Taxon	Slide Location
1	*Cymatiosphaera?* sp. A	GMUS 4254 A 008/106
2	*Fromea amphora*	GMUS 4214 A 008.3/104
3	*Fromea chytra*	GMUS 4272 A 019/114
4	*Fromea fragilis*	GMUS 4244-1 015/112
5	*Michrystridium harlandii*	GSC 401338 009.5/96.8
6	*Michrystridium* spp.	GSC 401343 004.5/97
7	*Veryhachium* spp.	GSC 401316 010/107
8	*Veryhachium* spp.	GMUS 4216-1 009.9/112
9	*Palambages morulosa*	GMUS 4490 A 008/116.5

PLATE 1









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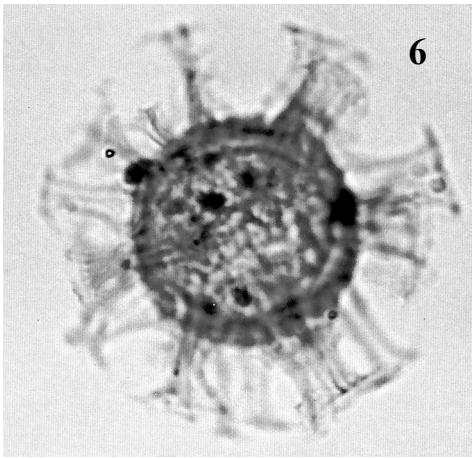

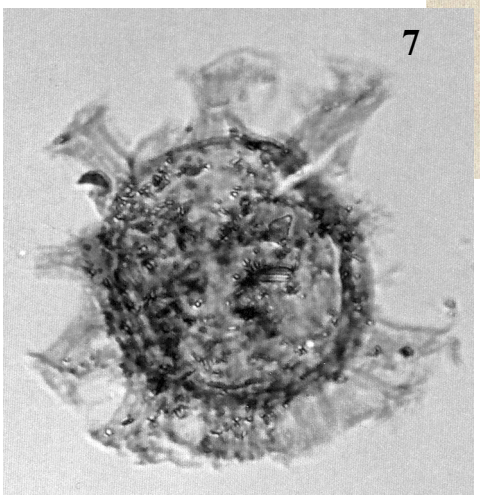

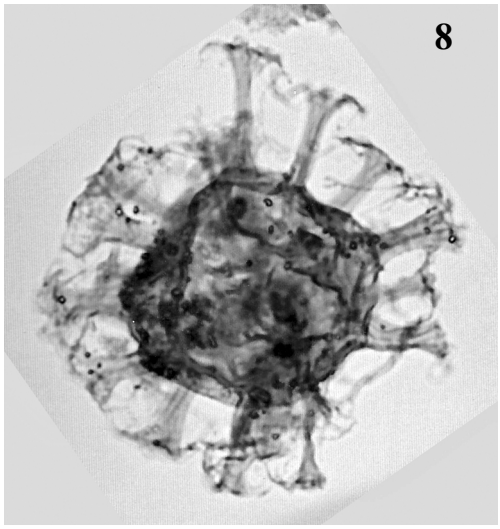

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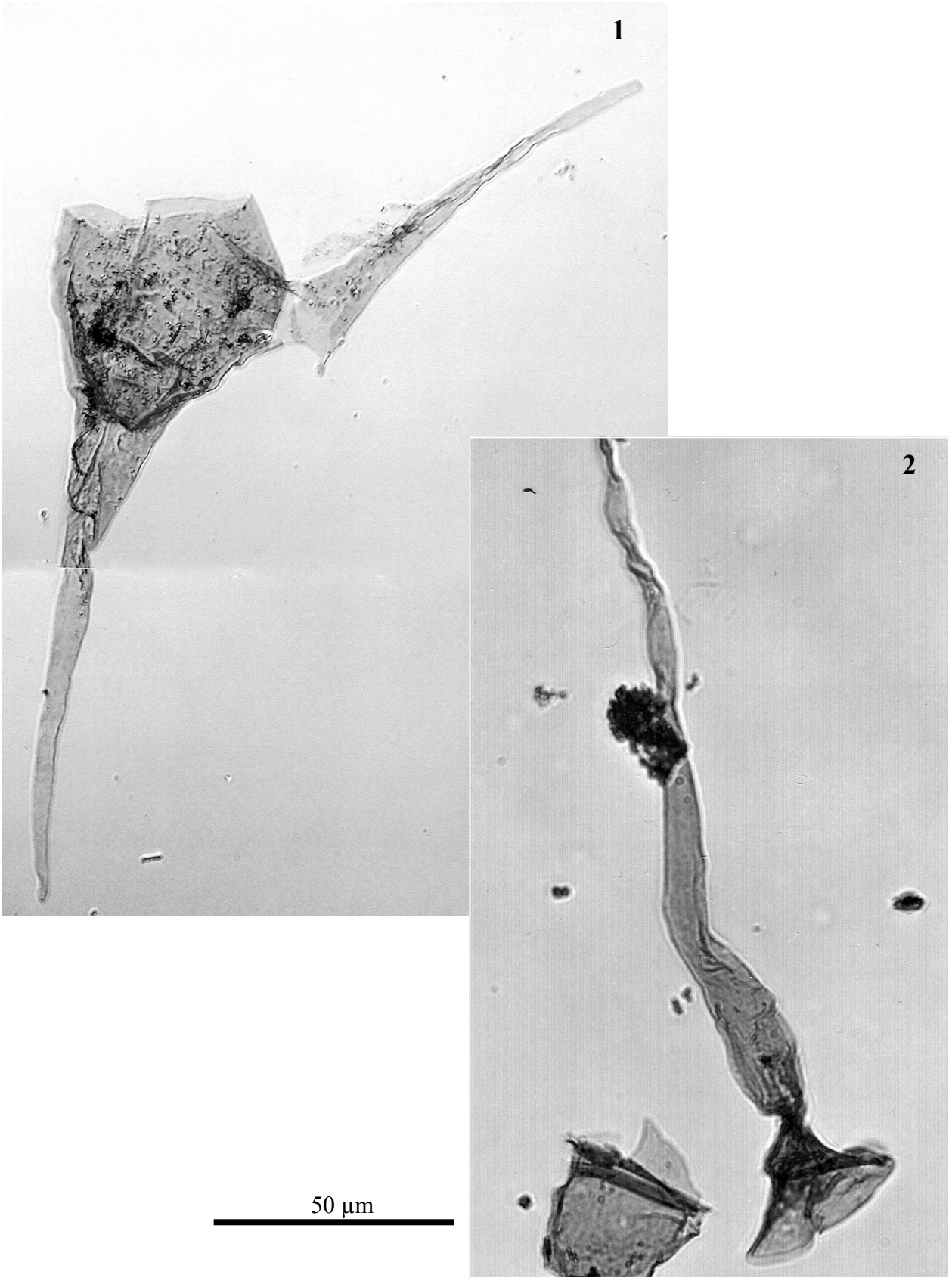

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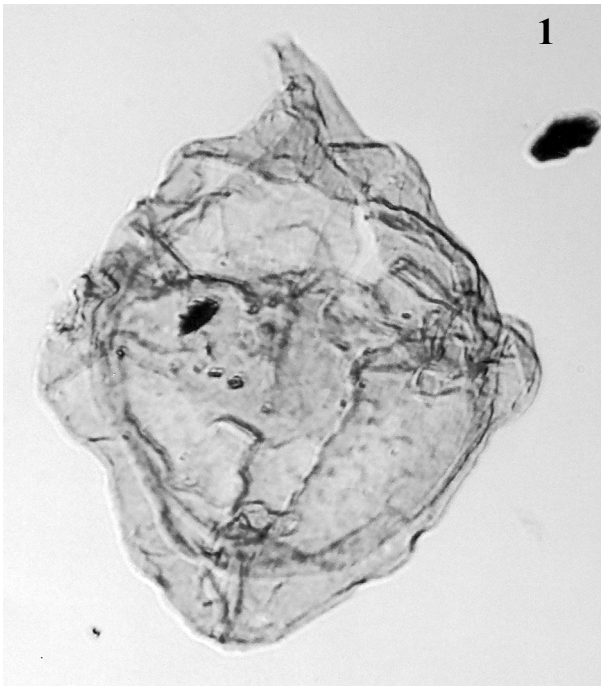

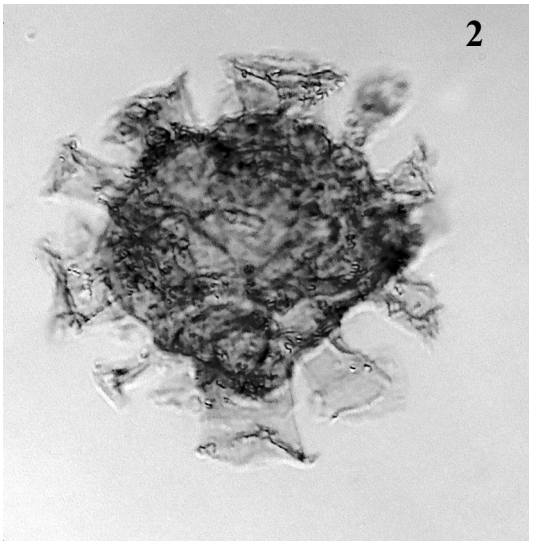

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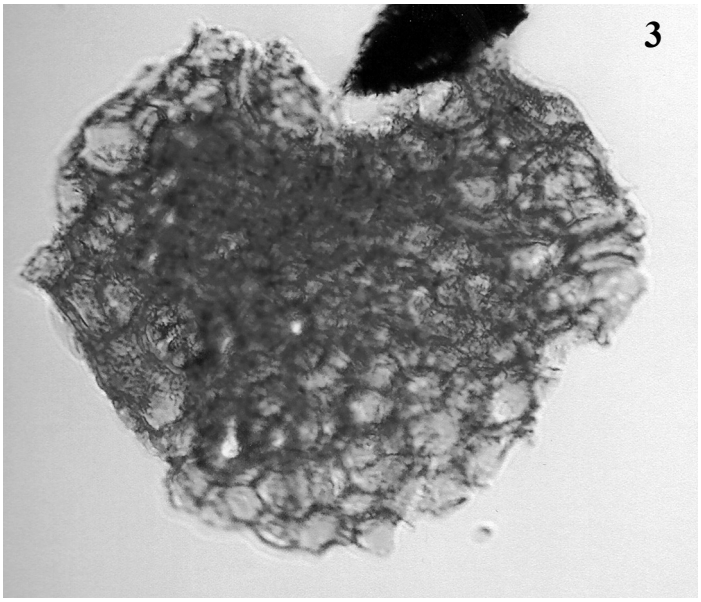

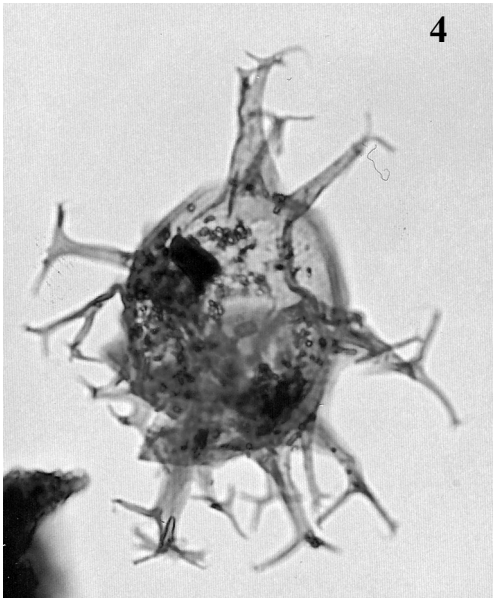

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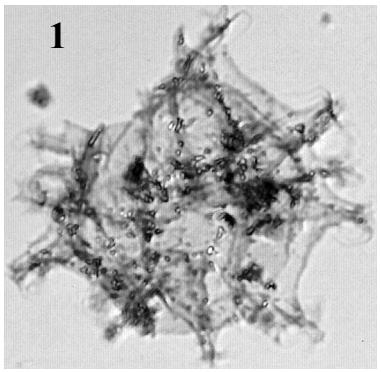

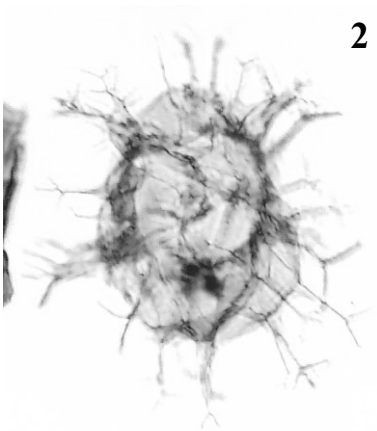

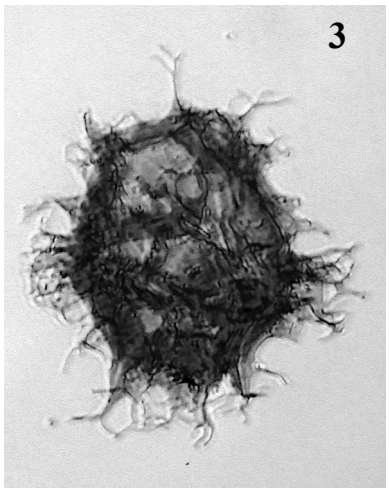

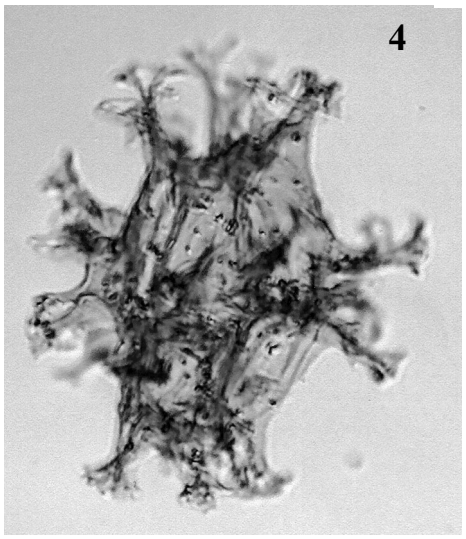

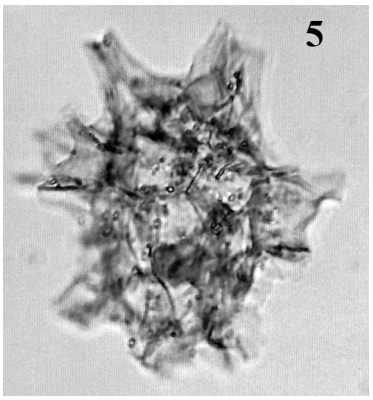

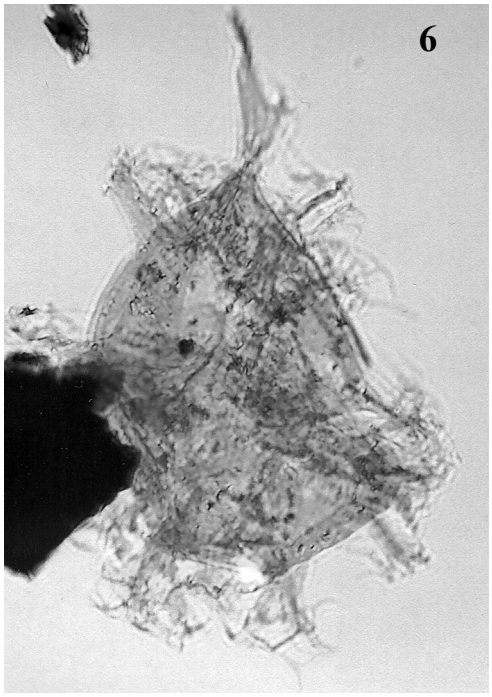

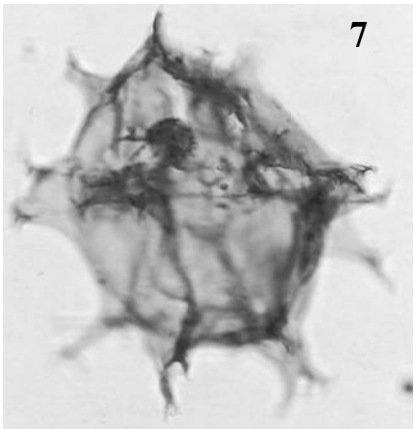

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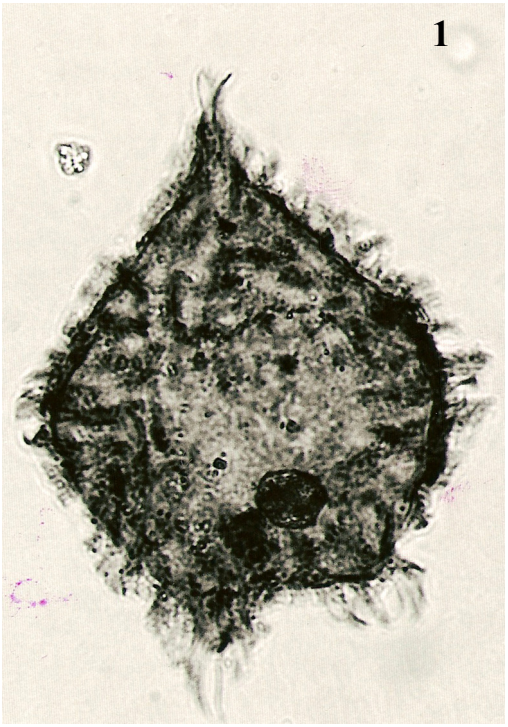

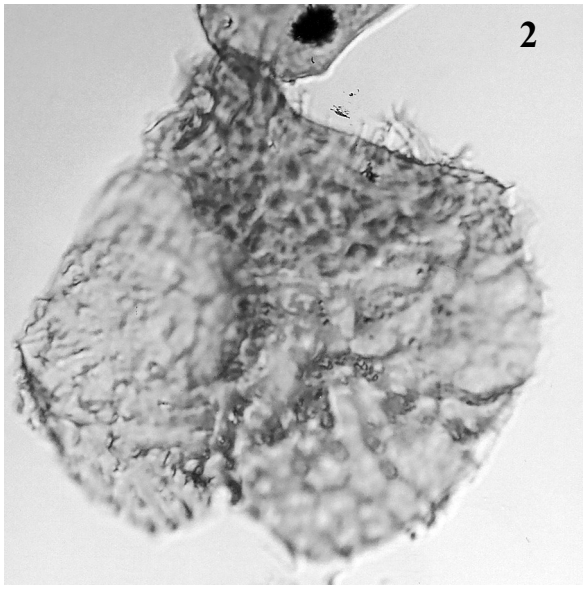

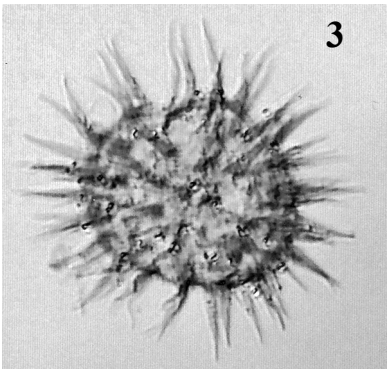

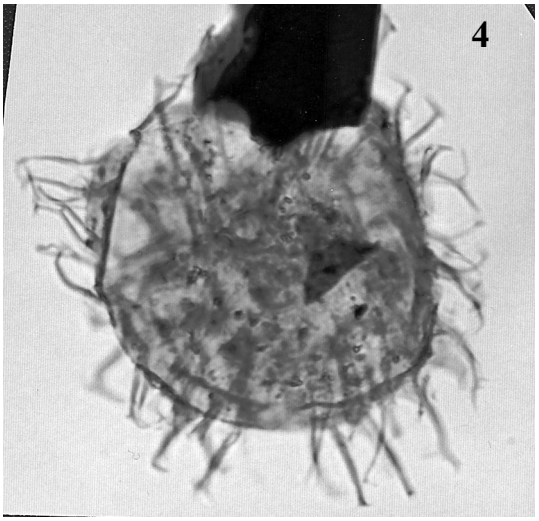

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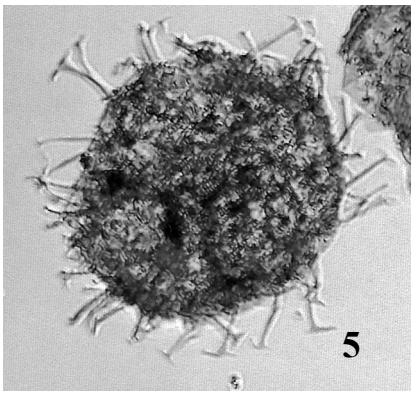

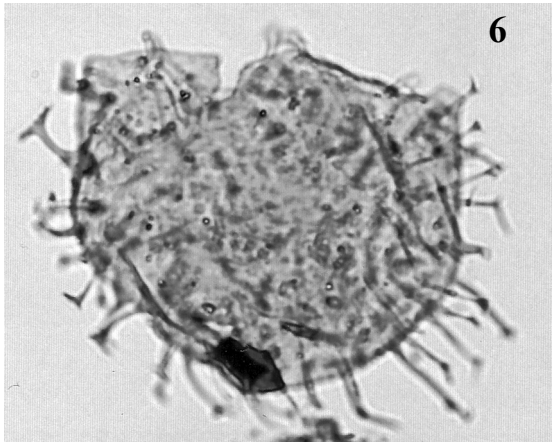

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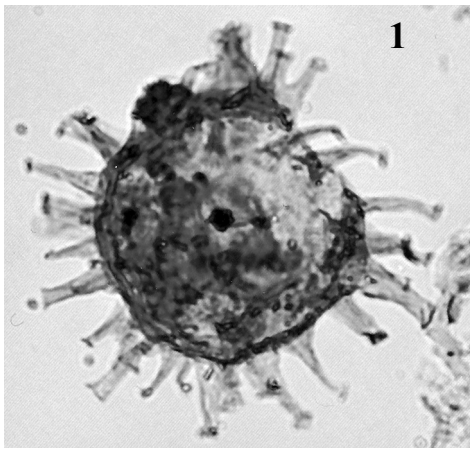

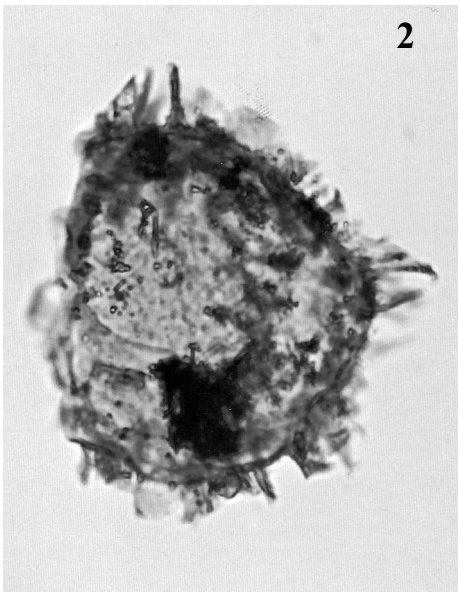

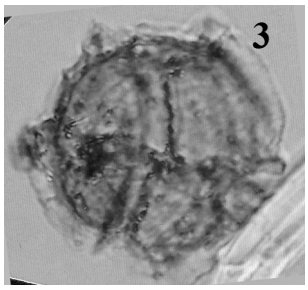

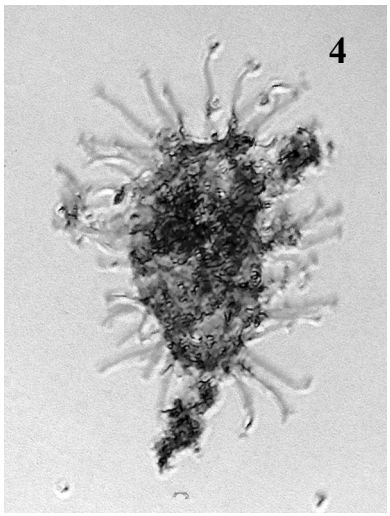

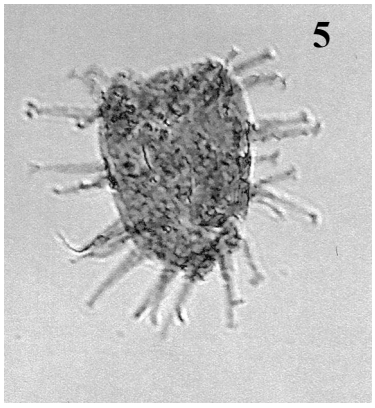

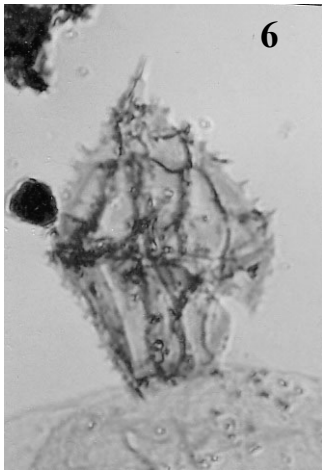

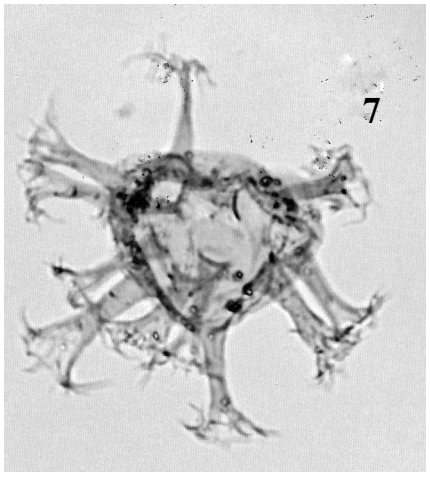

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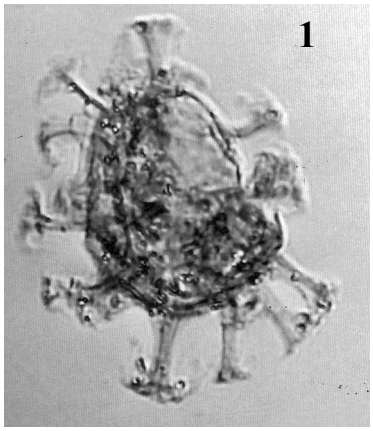

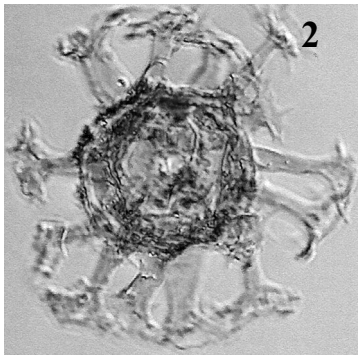

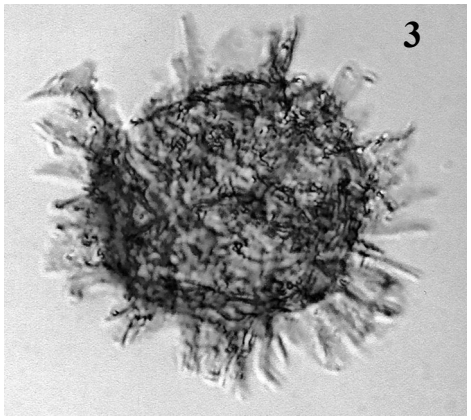

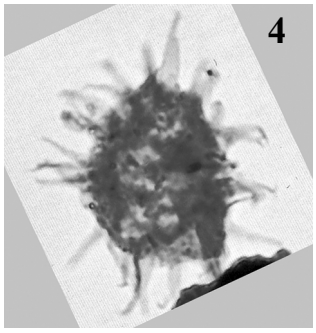

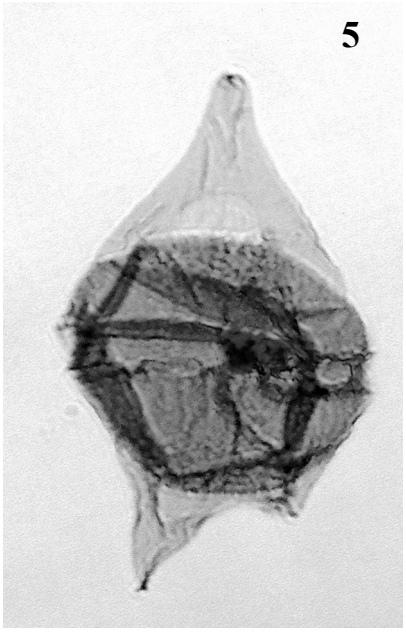

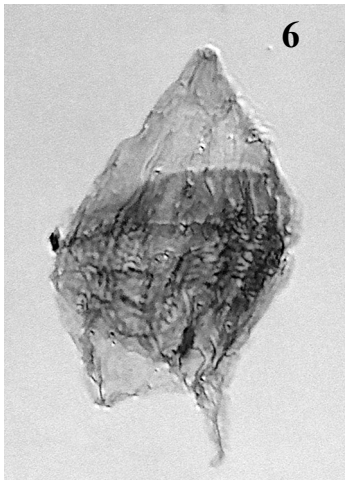

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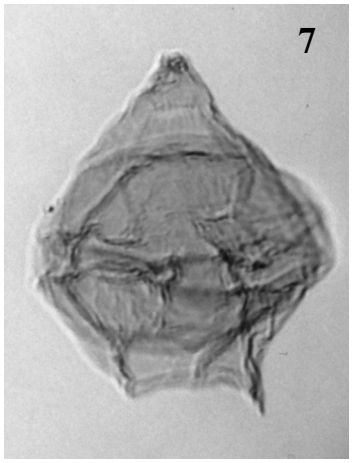
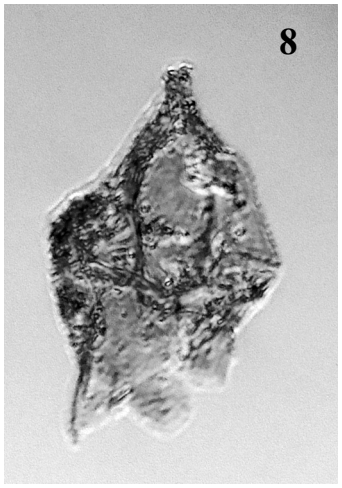




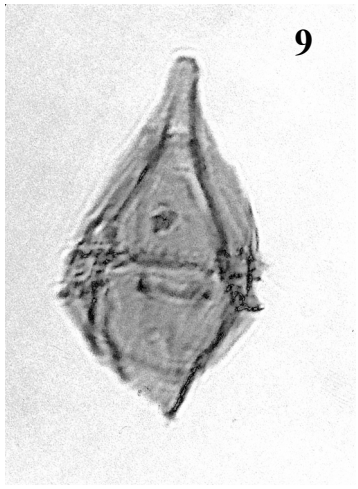
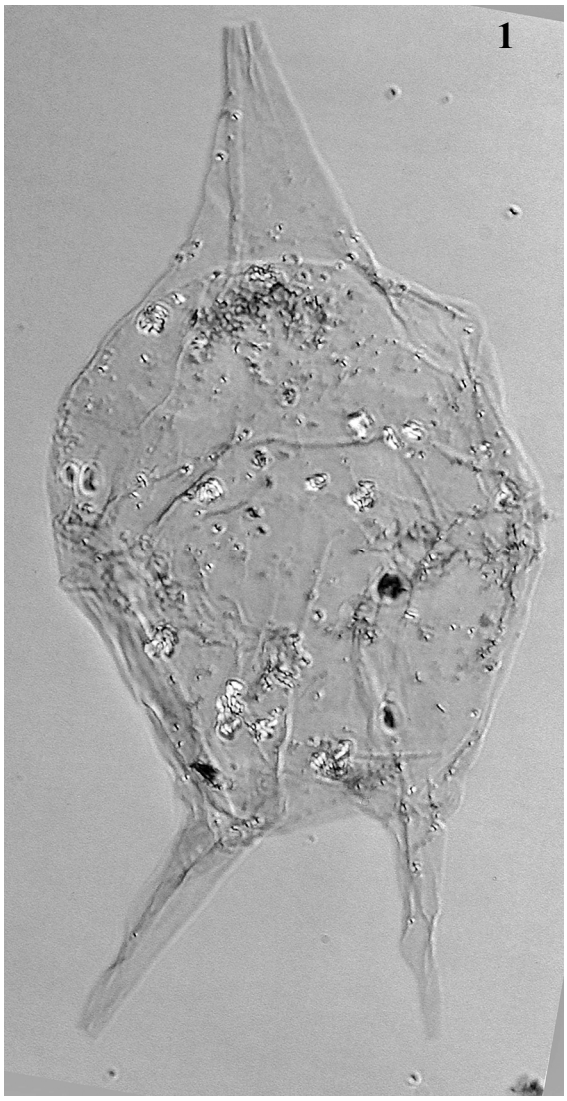
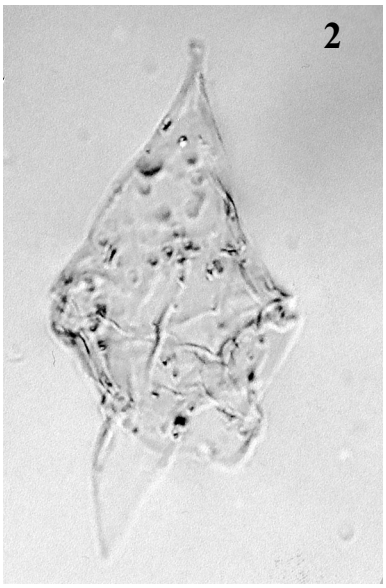
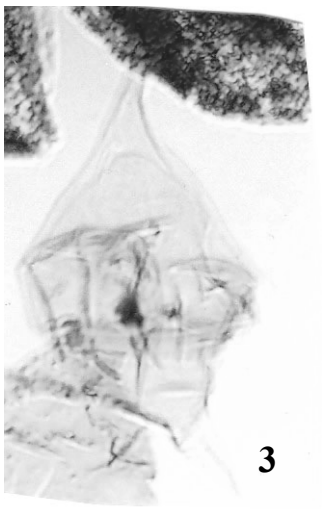


PLATE 8







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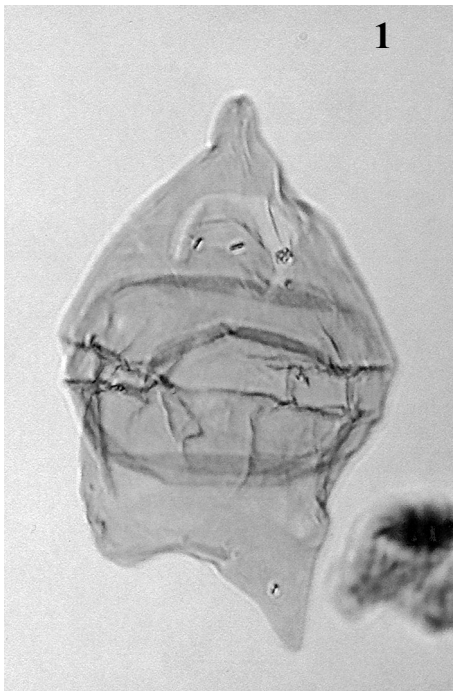

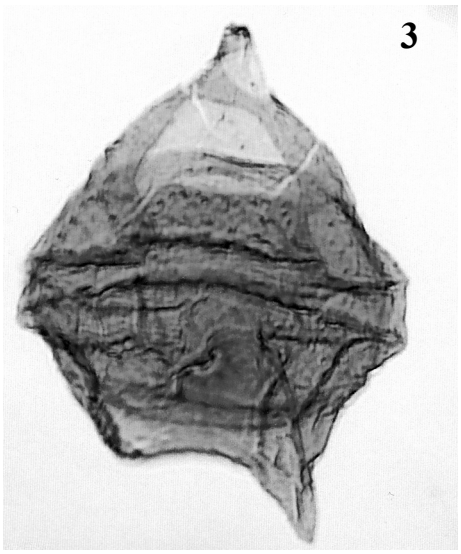

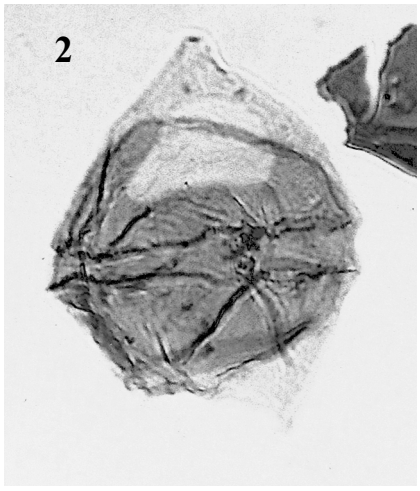

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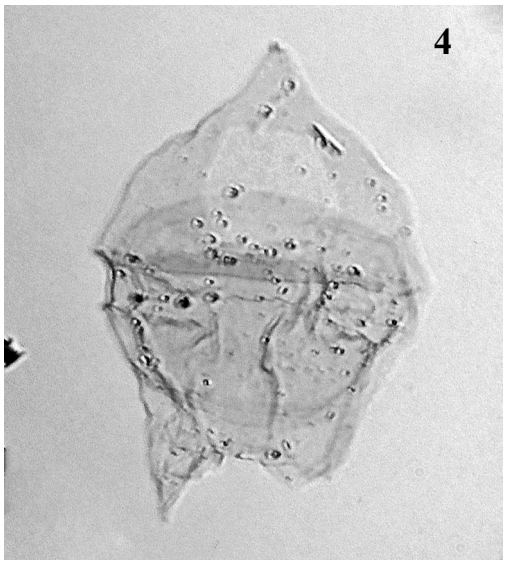


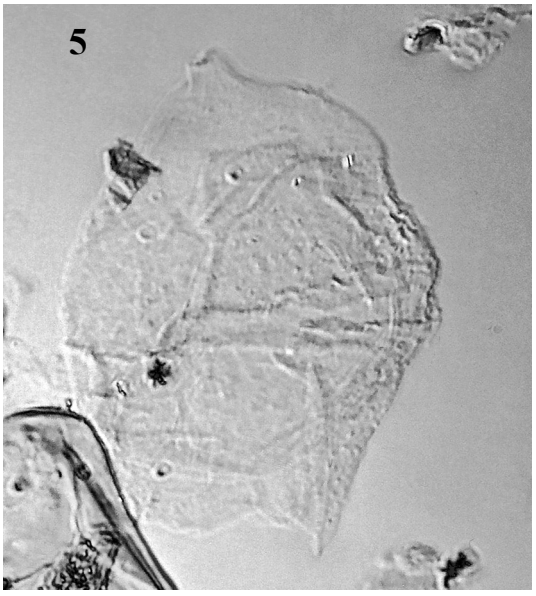
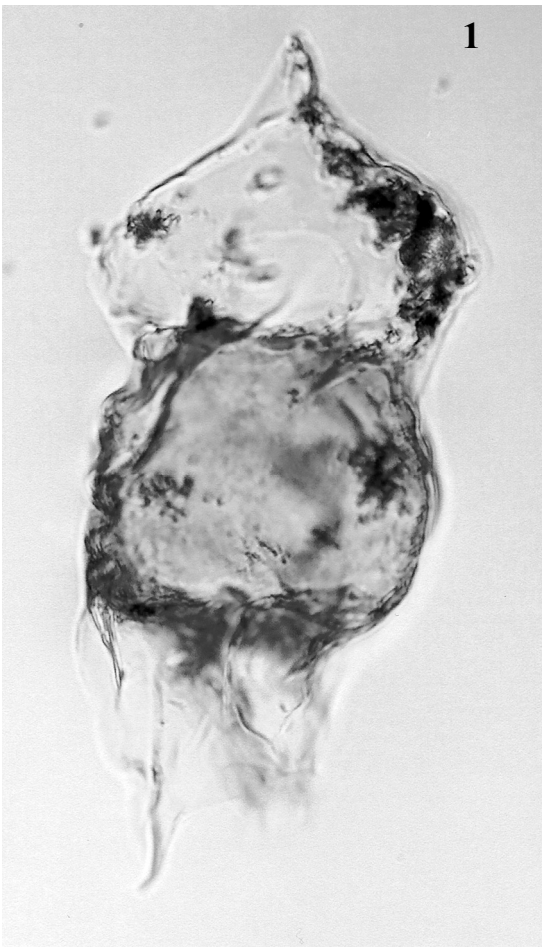
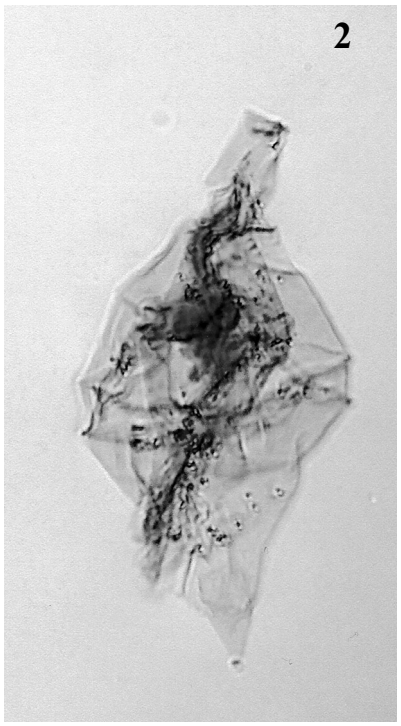


PLATE 10





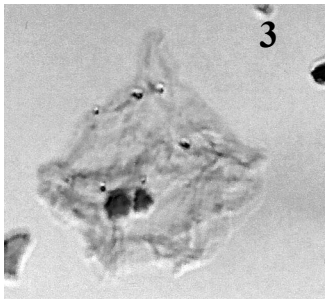


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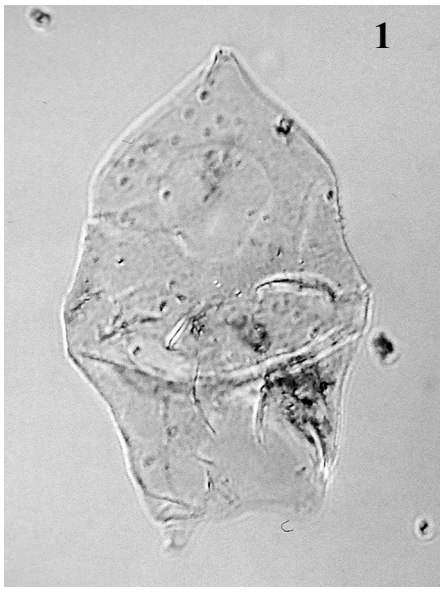
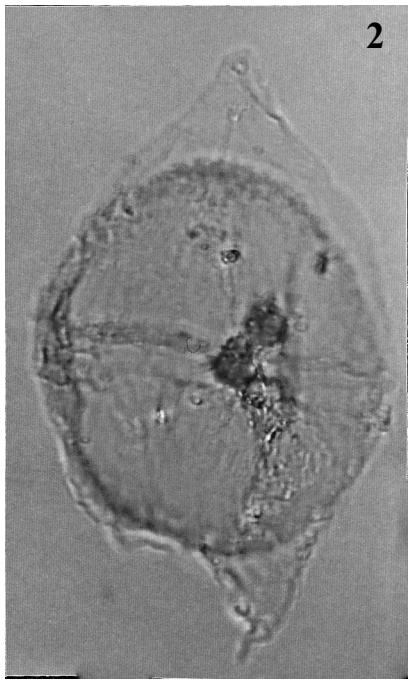
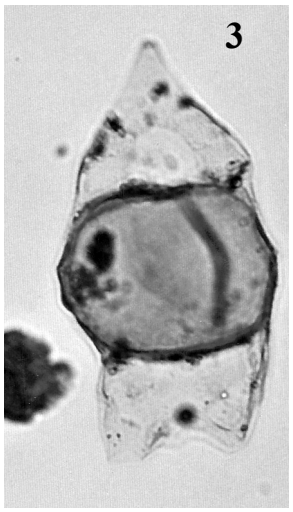
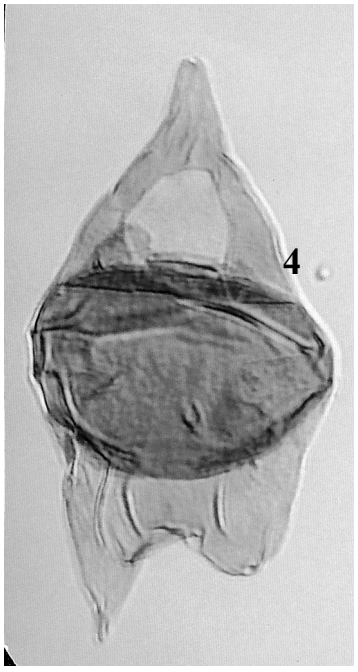
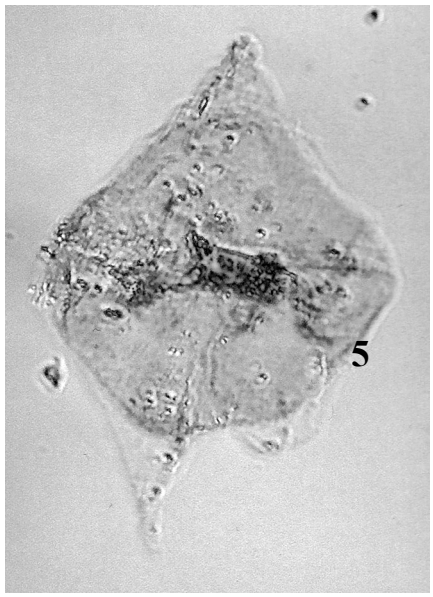
PLATE 11

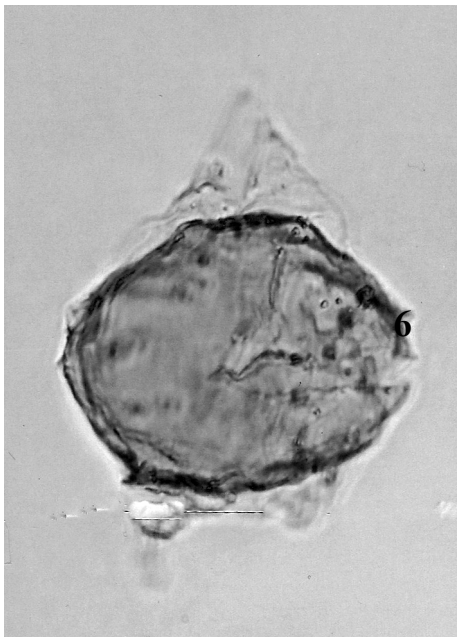






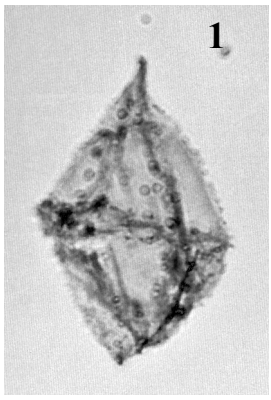


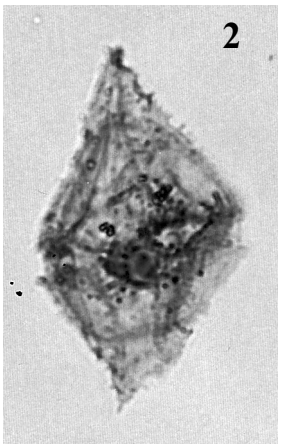


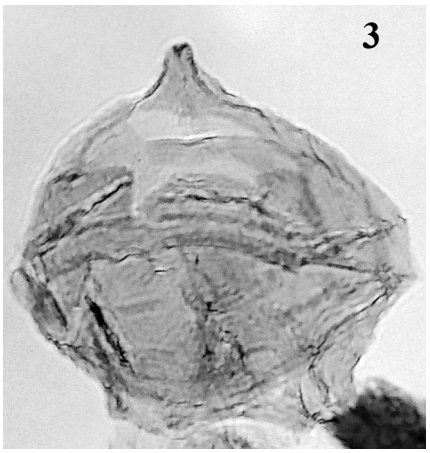


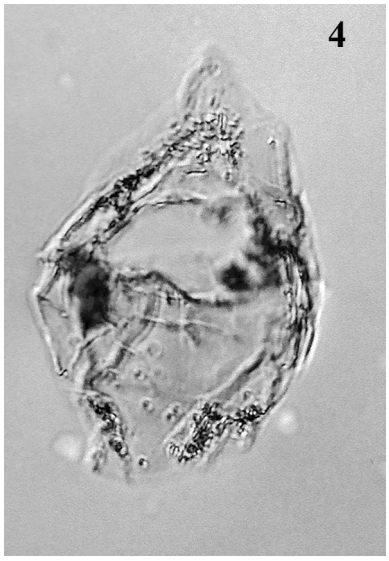
50 µm

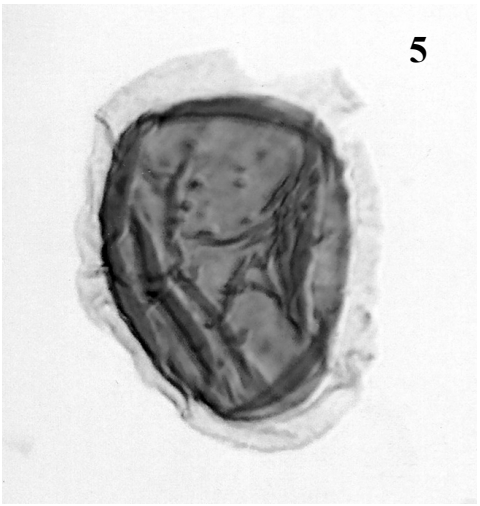
PLATE 12

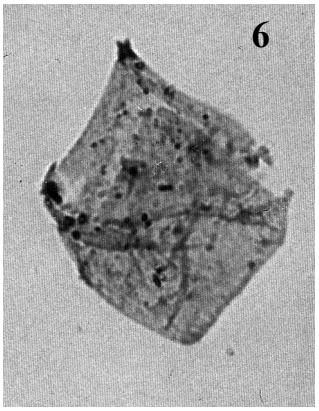


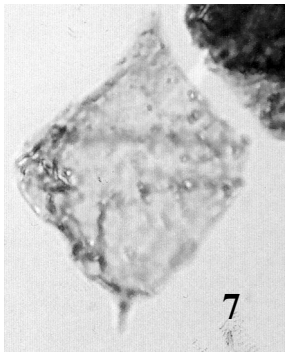


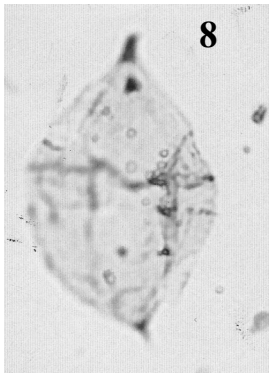


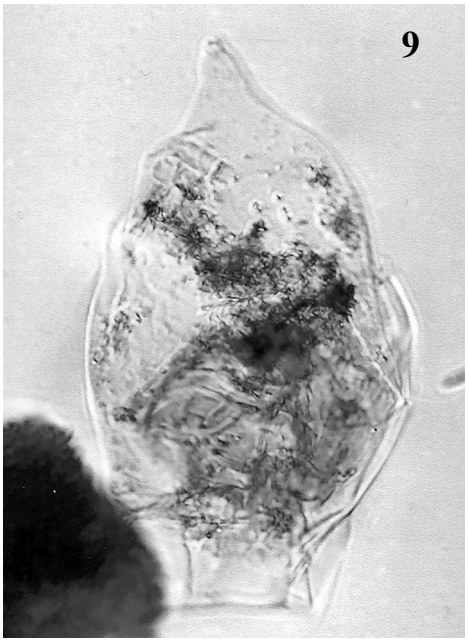






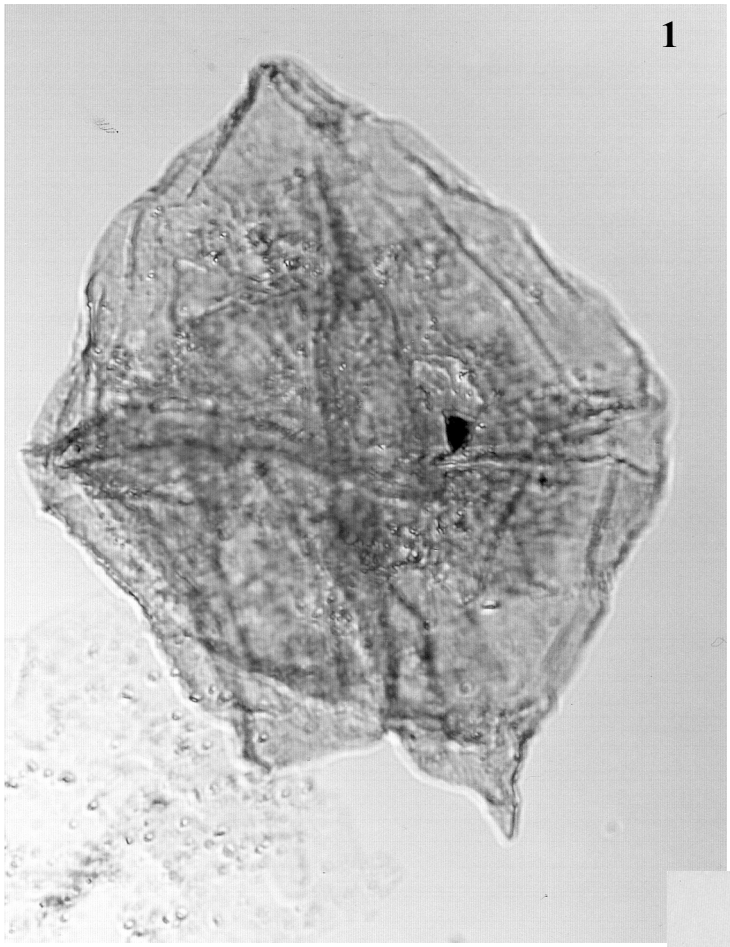


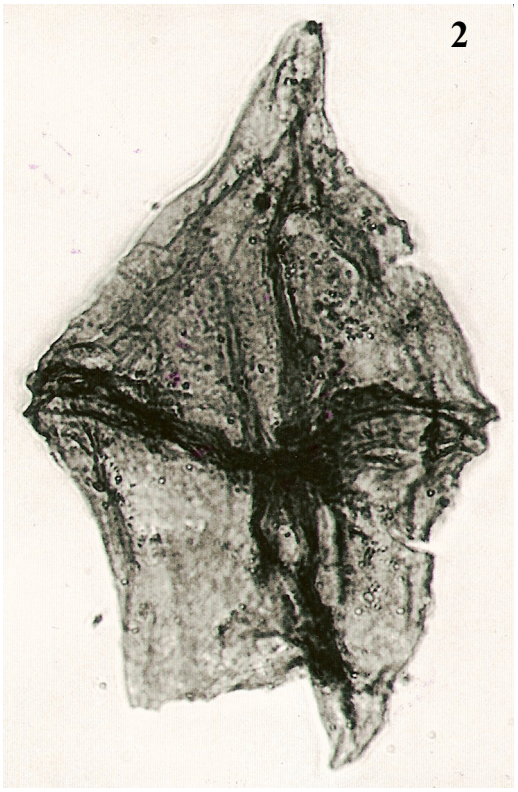


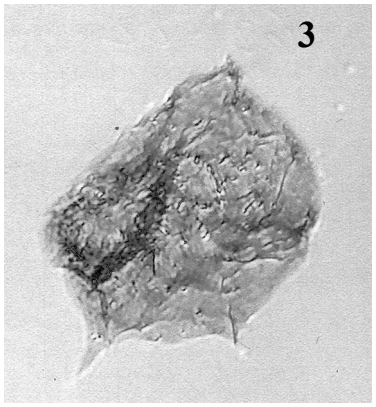


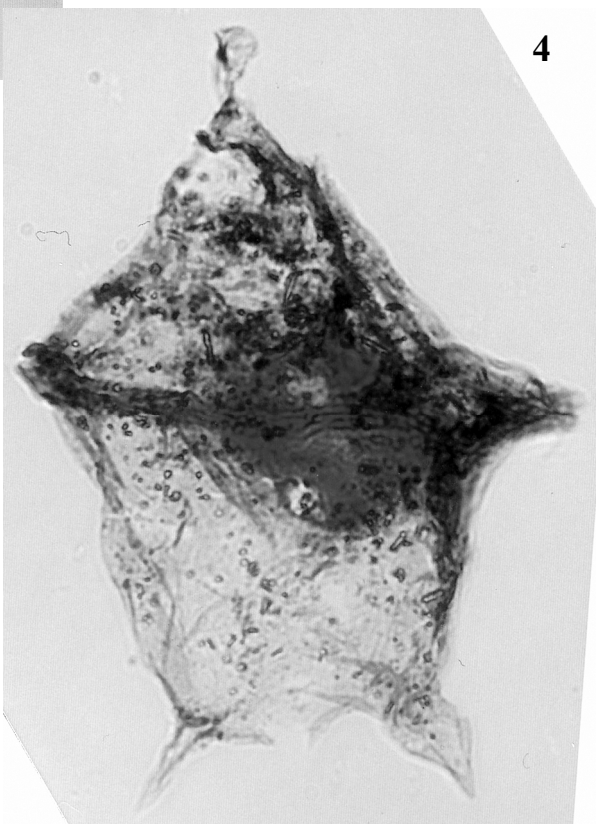
50 µm

PLATE 13



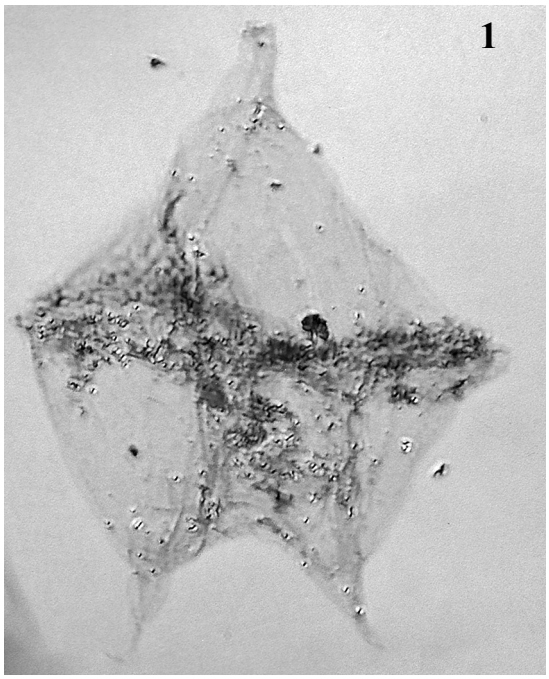


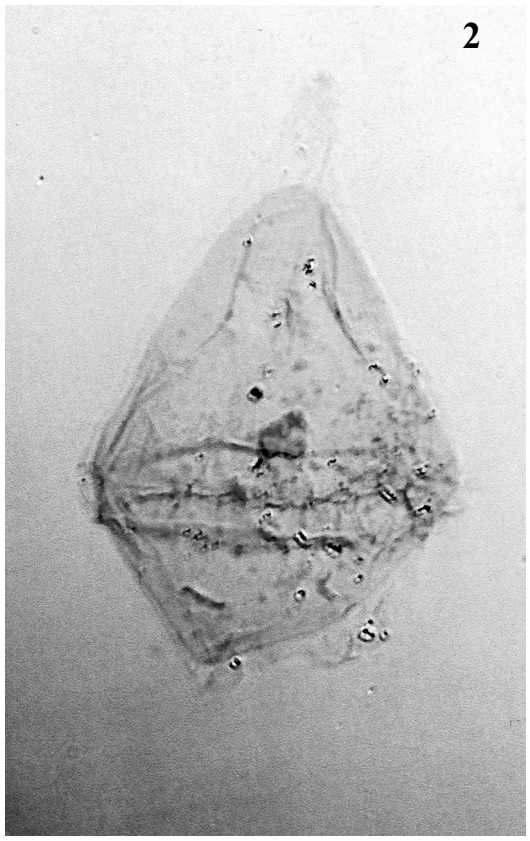


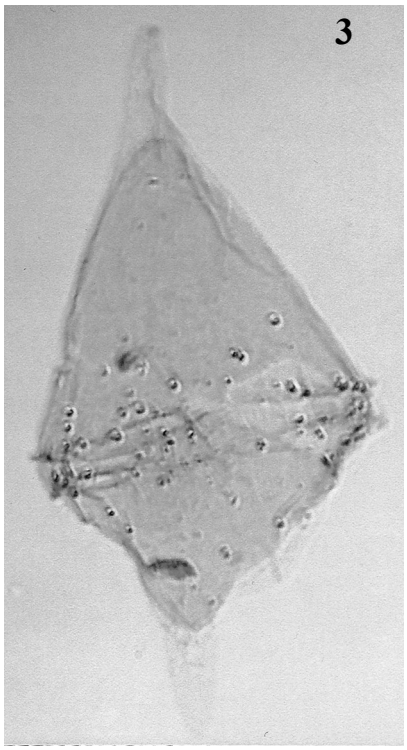


50 µm

PLATE 14

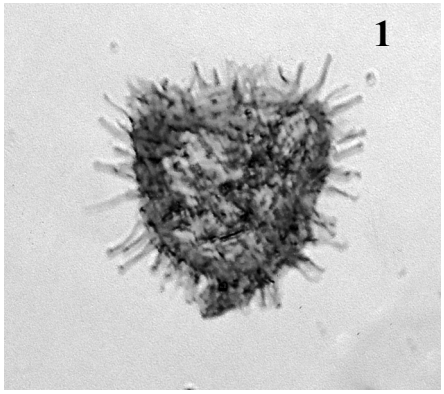


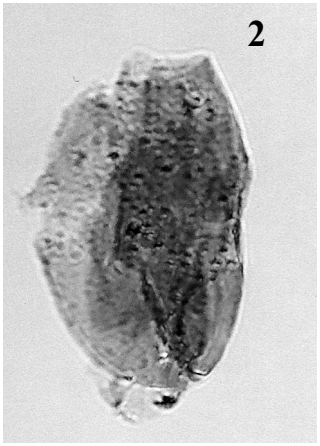


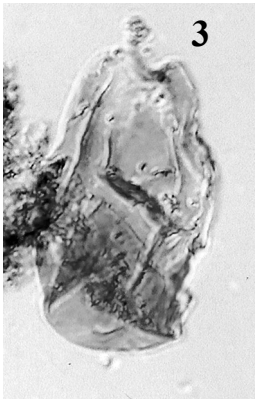


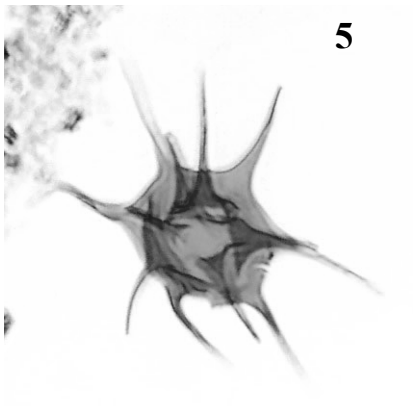
50 μm

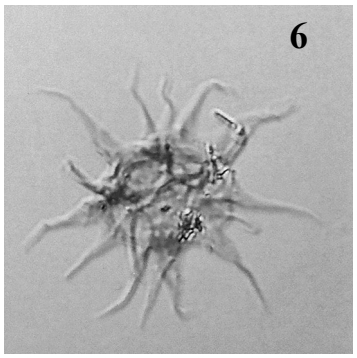
PLATE 15

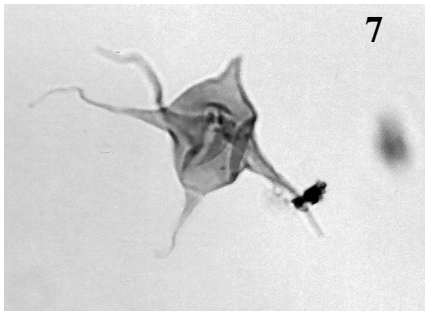


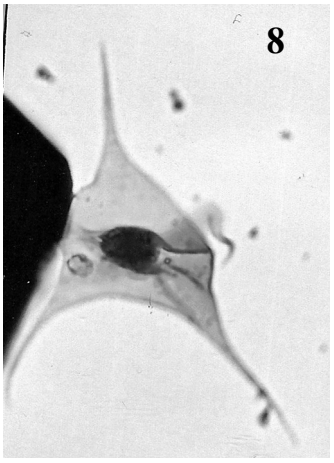


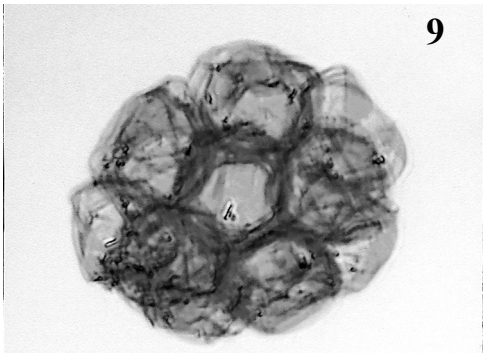












50 µm